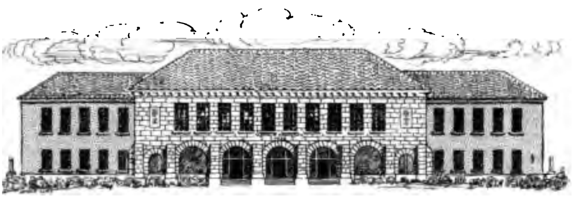
SSONS
IN
PHYSICAL GEOGRAPHY

CHARLES R. DRYER



Ohio River, near Madison, Ind. (Frontispiece.)

LESSONS

IN

PHYSICAL GEOGRAPHY

BY

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NEW YORK ·:· CINCINNATI ·:· CHICAGO
AMERICAN BOOK COMPANY

DR. PHYS. GEOG.

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PREFACE

This book has been written in the belief that physical geography is not only interesting and valuable in its subject matter, but is capable, when properly presented, of developing a scientific habit of mind. No attempt is made to discuss all the physical features of the earth, or those of any special region. The best type forms are selected and treated with sufficient fullness to give a clear and definite picture. From a study of the type general laws are developed, and the student is thus provided with a key for the solution of geographical problems wherever they may arise.

Each topic is treated inductively. The essential facts are first given, and the student is then guided to a knowledge of their causes, significance, and results. This plan makes it possible to avoid in some degree the vague generalizations which are characteristic of most text-books. The student is in possession of a sufficient number of facts to enable him to see the basis and appreciate the value of the generalizations which follow. A large number of realistic exercises are introduced which appeal to the actual or possible experience of the student. They are designed not for the purpose of discovery but of realization, and to give some idea of the methods and possibilities of geographic research. These exercises include both field and laboratory work.

No pains has been spared to make the book scientifically accurate and representative of the state of geographic

science at the opening of the twentieth century. Due prominence is given to recent developments, but not to the exclusion of any link in the chain which connects the face of the earth with man. Discussions of topics which have a special bearing upon human interests are introduced at intervals throughout the book, and the relations of the physical features of the earth to human progress are systematically treated in a final chapter.

The book has been written with a view to the needs of the teacher as well as to those of the student. Each topic is treated with sufficient fullness to enable the teacher to see its relation to other topics and to teach it intelligently. An unusually large number of illustrations have been selected with a view only to their teaching value. Appendixes give full instructions as to where good material and appliances for teaching may be obtained and how to use them. A bibliography of nearly all the geographical literature available in English is added for the use of students, teachers, and those wishing to provide a good working library of the subject.

In the arrangement of topics the logical order of the science is modified by the pedagogical order of presentation to students. As a rule a topic is introduced where it is most needed in teaching; but in many cases the order may be modified to suit individual or local conditions without inconvenience. Difficulties have not been avoided, but constant effort has been made to find the best way of overcoming them. The best method of learning is also the best method of teaching, and it is the hope of the author that this book may prove to be a substantial help in both.

TERRE HAUTE, INDIANA.

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BOOK I. THE PLANET EARTH

Alone, unpiloted, unswerving aye,
The blind old earth spins on its trackless way.

CHAPTER I

THE EARTH IN SPACE

The Earth appears to be Flat. — One who lives in a moderately level country sees the earth around him as a flat disk which stretches away in every direction to a circular rim or horizon. Above the disk he sees the heavens or sky, like a dome or inverted bowl, with its edge resting all around on the rim of the earth. Every day he sees the sun rise above the edge of the earth on one side, pass over the arch of the sky, and disappear below the edge on the other side. At night the moon appears to follow a similar path, and the sky is studded all over with myriads of bright points. Sometimes clouds float between earth and sky and hide sun, moon, and stars. In a hilly country it is necessary only to climb up to a high point to observe the same appearances, except that the earth disk seems larger and the sky dome more lofty.

From any point of view it is evident also that objects in the distance look smaller than similar ones near by. To one looking along a railroad track, the telegraph poles appear to grow shorter and the rails nearer together, until they meet on the horizon. The same is true of the trees and houses on a long street. A horse or a man a mile away looks less than half his real size. Any object, how-

ever large, even a mountain, if far enough away, may appear very small or be indistinguishable. On a bright, clear day distant objects look larger and nearer than on a dark day. A burning brush pile at night can be seen much farther than the unlighted pile by day. So the appearance of distant objects varies with their size and with the quantity of light that comes from them.

Realistic Exercises. — Clear and definite ideas of distance can be acquired only by experience and practice. The student should give himself a thorough training with yardstick and tapeline. Let him measure his book, the desk, schoolroom, building, yard, width of the street, city square, etc., not neglecting to measure heights as well as horizontal distances. He should practice estimating distances by the eye and then correct his estimates by measuring. A very convenient way of measuring is by the step or pace. Walk a hundred steps and measure the distance: do this repeatedly until the ability is acquired to step a known and uniform space. In a short time any one can learn to measure distances quite accurately by counting steps. Let one half of a class arrange themselves in line at regular intervals of one hundred yards, while the other half observe the apparent distance and size of the individuals.

The Curvature of the Earth. — More than two thousand years ago scientific observers discovered that the surface of the earth is not flat, as it seems, but curved. When viewed from the water level on the shore of the ocean or of any body of water several miles across, the lower part of a ship or a tree, house, or other object at the same level near the opposite shore is hidden behind the curve of the water surface. At a distance of one mile the object is hidden to the height of eight inches, at two miles four times eight inches, at three miles nine times eight inches, and so on, according to the square of the number of miles. If the observer ascends a hill or

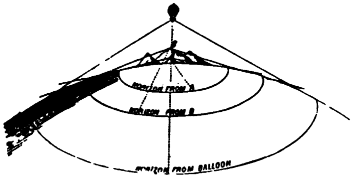


Fig. 1.

building, he can see farther over the curve; that is, the circle of the horizon enlarges. This is true also upon land. On a plane surface the horizon would be at an indefinite distance and would not retreat as the observer ascends.

At places east of us the sun rises and sets earlier, and at places west of us later, than where we are. At Philadelphia the sun rises an hour before it does at St. Louis, which is about eight hundred miles farther west. If the surface of the earth were flat, the sun would rise at all places at the same moment and set at the same moment. If the earth's surface were a plane, sun time would be the same at all places. The sun is so far away that it would appear at the same angle from Philadelphia, St. Louis, and Denver, and if it were noon at one of these places, it would be noon at the others. Vertical lines at the three places would be parallel. But when it is noon at St. Louis it is 1 P.M. at Philadelphia and 11 A.M. at Denver. Vertical lines at the three places converge downward. Therefore the surface of the earth along an east and west line is curved.

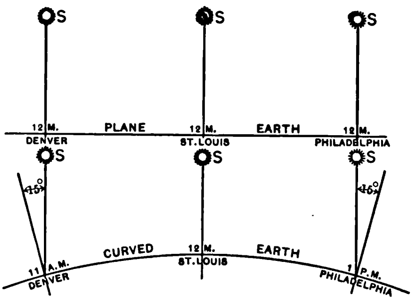


Fig. 2.

At a place where the sun is directly overhead at noon an upright post casts no shadow. At places to the north or south an upright post at noon casts a shadow, the length of which becomes greater as the distance from the place of no shadow increases. If the earth's surface were a plane, the sun at noon, on account of its great distance, would appear everywhere at the same angle, and an upright post would cast a shadow of the same length everywhere.

To one who travels north or south, stars previously invisible rise in front of him, while stars behind him disappear below the horizon. The plane of the horizon tilts as he goes, sinking before and rising behind, which is just what must occur on a curved surface. Thus a person at *A* (Fig. 3) can see the star *x*, but not *y* and *z*, while a person at *C* can see all three of the stars. Hence the surface of the earth along a north and south line is curved.

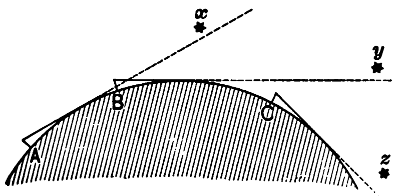


Fig. 3.

The shadow of the earth cast upon the moon during an eclipse always has a circular outline, on whatever side of the earth the moon happens to be. Only a spherical body casts a circular shadow in every position.

Lastly, the form and size of the earth have been accurately measured by various methods. The mean equatorial diameter has been found to be 7926 miles, the polar diameter 7900 miles, and the mean circumference 24,860 miles.

Realistic Exercises. — Ascend to the highest point you can reach, the tower or roof of a building, or the top of a tree or hill. How does the horizon change as you go up? If possible, observe distant objects across a level stretch of country or a large body of water. If you travel several hundred miles east or west, how do you have to change your watch to make it agree with the time of the places you visit?

Raise a lamp or candle slowly from the floor to the level of a table: does its light strike all the objects upon the table at the same moment? Lower it: does its light disappear from all parts of the surface of the table at the same moment?

If there is a hill in your vicinity, even a small one, stand at the foot of it and note the stars just visible above its top. Ascend the hill and notice how those stars rise higher above it and new stars come in sight. Descend upon the opposite side and notice how the stars disappear

behind the hill. Other objects, as trees and buildings, may be observed instead of stars. The curve of the hill produces in a small space the same effect as the curve of the earth.

Consult the almanac for the time when an eclipse of the moon will occur, and observe the circular shadow of the earth. Hold a ball in various positions between a lamp and a wall: if the line from lamp to ball is perpendicular to the wall, what is the shape of the shadow? Substitute various other objects for the ball, and compare results.

The Starry Heavens. — If we observe the position of the conspicuous group of stars in the northern sky called the Great Dipper,[1] and then look for it again a few hours later, we shall find that, while the stars still form the outline of a dipper, the whole group has changed its position.

By repeated observations we can map out in the heavens the path along which it is traveling and learn its speed, so that we can predict about where it will be in another hour or two. In this way, from a few evenings' watching, it will be plain that the stars in the northern sky appear to wheel around a central point, in a direction opposite to the motion of the hands of a clock (counterclockwise), once in about twenty-four hours. The central point is near a not very bright star standing alone in a direct line with the outer two stars of the Dipper, which are called the Pointers because they always point toward the central star, called

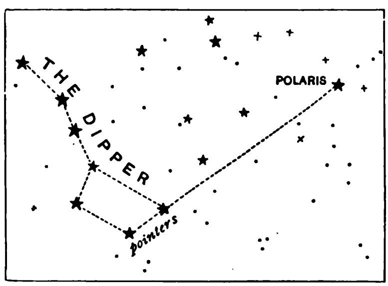


Fig. 4.

[1] The Dipper is near the horizon due north, Sept. 22, at midnight; Oct. 23, at 10 P.M.; Nov. 7, at 9 P.M.; Nov. 22, at 8 P.M.; Dec. 7, at 7 P.M. In the northeast, Dec. 22, at midnight; Jan. 20, at 10 P.M.; Feb. 4, at 9 P.M.; Feb. 19, at 8 P.M. On the meridian above the Polestar, March 21, at midnight; April 20, at 10 P.M.; May 5, at 9 P.M.; May 21, at 8 P.M.

Polaris or the Polestar. The circumpolar stars inside the circle described by the Dipper never set in our part of the world.

If we watch some conspicuous group of stars like Orion, which in the autumn months rises early in the evening[1] directly in the east, we shall see it slowly mount the sky, pass a little south of the zenith, and, about twelve hours after its rising, set directly in the west. The other stars outside the circle of the Dipper will be found to rise somewhere on the eastern horizon, follow a longer or shorter path across the heavens, and set somewhere on the western horizon. *The whole starry heavens seem to be turning about an axis which passes through the Polestar,* just as an open umbrella may be turned about its stick. If bits of paper are gummed to the inside of the umbrella, and it is held close to the head and turned, the papers will perform the same kind of a motion as the northern stars. If we had a large hollow globe with stars fastened all over its inner surface, and could place ourselves at the center of it while it rotates around us, it would imitate the apparent motion of all the stars, and we could see the whole path of each. The great hollow globe which seems to carry the stars, and at the center of which our home on the earth seems to be placed, is called the *celestial sphere.*

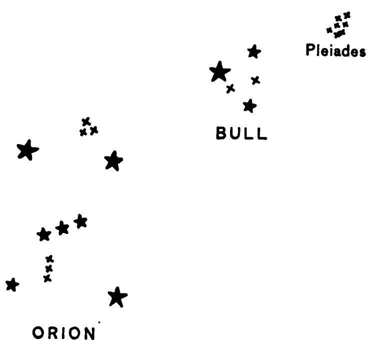


Fig. 5.

[1] Orion is just rising due east, Sept. 22, at midnight; Oct. 23, at 10 P.M.; Nov. 7, at 9 P.M.; Nov. 22, at 8 P.M.; Dec. 7, at 7 P.M. On the meridian, south of the zenith, Dec. 22, at 11 P.M.; Jan. 20, at 9 P.M.; Feb. 4, at 8 P.M.; Feb. 19, at 7 P.M.

The Apparent Path of the Sun. — The sun appears to revolve with the celestial sphere, but its path changes a little from day to day. On March 21[1] (Vernal Equinox) it rises due east, passes south of the zenith at noon, and sets due west. After March 21 it rises farther and farther north of east, and sets farther and farther north of west until June 21,[1] when it shines into our north windows for some time

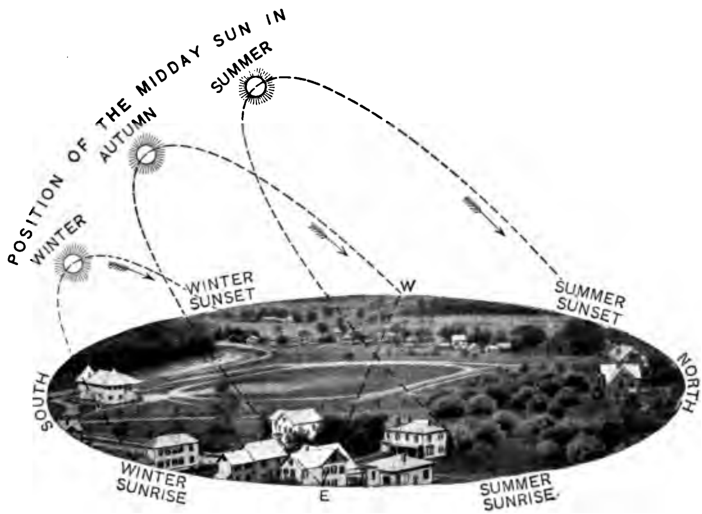


Fig. 6. (From Todd's New Astronomy.)

morning and evening, though it still passes south of our zenith at noon. Then the path of the sun begins to move back southward. On September 23[1] it is just where it was on March 21, and on December 22[1] it rises farthest to the south of east, and sets farthest to the south of west.

Realistic Exercises. — Choose some convenient place where the view is as little obstructed as possible. An open field is best, but an upper room or tower or roof of a building is good. From this spot determine the four cardinal points on the horizon: the point directly below

[1] These dates vary a day or two in different years and centuries.

the sun at noon is south, the point directly below the Polestar is north, and the sunrise and sunset points on September 23 and March 21 are east and west respectively. Always standing in the same place, observe once every week or ten days the point on the horizon where the sun rises or sets or both; also its distance above the south point at noon. Valuable observations may be made of the sunset point from a west room with several windows. Mark upon the floor a spot which commands as wide a range of the western horizon as possible. Observe from it the movement of the sunset point north or south from week to week. The extreme points reached on June 21 and December 22, and the middle point on September 23 and March 21 are especially important, and their direction should be marked upon the window sill.

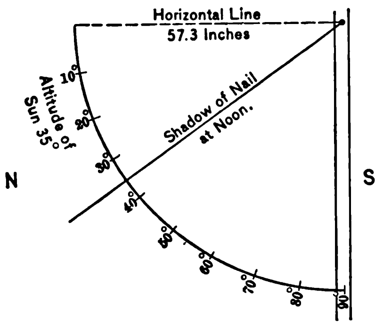


Fig. 7.—A "heliotrope."

The height of the sun at noon may be advantageously observed from a south window. Mark upon the floor from week to week the point reached by the shadow of the window sill at noon, or measure its distance from the wall and record it with the date. This work may be done more accurately by the use of a device for measuring angles. Find a building or fence the west side of which is in a north-south line. This may be determined at night by observing whether it is in line with the Polestar. At a point near the south end, and about six feet from the ground, drive a long nail horizontally so that it will project several inches. With a carpenter's leveling board, or with a square and plumbline, draw a horizontal line at the level of the nail, locate upon it a point 57.3 inches north of the nail, and mark it with a tack (Fig. 7). Fasten to the nail one end of a wire or a string which does not stretch, and with a pencil draw an arc downward from the tack to a point below the nail This will be a quadrant of a circle three hundred and sixty inches in circumference, and the degrees, each one inch long, should be marked and numbered from the tack downward, and each degree divided into fourths or arcs of 15′. About noon, at the moment when the sun first shines upon the west side of the building, note the point

where the shadow of the nail falls across the quadrant. The angle between the shadow and the horizontal line will be the altitude of the sun, or its angular distance above the south point of the horizon. The angle between the shadow and the vertical line will be the angular distance of the sun from the zenith. The altitude should be read and recorded once a week or ten days for at least six months.

Rotation of the Earth. — For thousands of years even the wisest men believed the earth to be the center of the universe, and the sun, moon, and stars actually to revolve around it as they appear to do. The sun was supposed to be a small hot ball a few miles distant, and the stars to be only bright points; therefore the velocity with which they must travel to complete a revolution around the earth every twenty-four hours did not seem so enormous to the ancients as it would to us. During the sixteenth and seventeenth centuries, the discoveries of Kepler, Galileo, and Newton[1] proved that the earth-center (*geocentric*) theory of the universe is erroneous, and that the heavenly bodies appear to revolve around the earth from east to west because the earth is rotating from west to east upon an axis, the north end of which points toward the Polestar. The earth makes one complete rotation upon its axis in 23 h. 56 m. 4.09 s.

Realistic Exercises. — The proof that the apparent motions of the heavenly bodies are due to the rotation and revolution of the earth belongs to astronomy rather than to geography, but these motions may be realized in several ways. If we watch the sunset closely, as the face of the sun appears to sink below the horizon, it is easy to see how in reality the horizon is rising between us and the sun. Again, as the face of the full moon appears to rise gradually above the horizon it is easy to see that the appearance is due to a sinking horizon. That is, as we watch the sun, moon, and stars rise, march from east to west, and set, we are really seeing the earth rotate from west to east.

When riding rapidly upon a railroad train notice how objects in the landscape appear to be rushing by in the opposite direction. When

[1] Read about these men in the encyclopedia.

sitting in a car, can you always tell whether a car upon the next track is moving one way, or your own car the other way?

Revolution of the Earth.—The earth travels along a nearly circular path through space at an average distance of nearly 93,000,000 miles from the sun. The circumference of this orbit is 584,600,000 miles. The earth revolves once around the sun (from one Vernal Equinox to the next) in 365 d. 5 h. 48 m. 46 s. About how many miles does it travel in its orbit each second? The earth's orbit is an ellipse having the sun at one of the foci. On January 2, the earth is nearly 91,500,000 miles from the sun, and on July 3, nearly 94,500,000 miles. The diameter of the sun is about 880,000 miles, or 110 times the earth's diameter, and the mean radius of the earth's orbit is 105 times the sun's diameter.

Realistic Exercises.—In a room having an unobstructed floor space sixteen feet in diameter drive a small nail into the floor in the middle of the space. On each side of it in a north-south line drive another nail at a distance of an inch and a half. These nails should project an inch or two above the floor. Take a string which does not stretch easily, double it, and tie the ends so as to make a loop 94½ inches long. Place one end of this loop around the two nails, and with a pencil at the other end draw upon the floor an ellipse having the nails for its foci. Around the north nail draw a circle eight ninths of an inch in diameter. The circle represents the sun, and the ellipse the orbit of the earth in correct proportion, the scale being one inch to a million miles. A proportional earth would be .008 inch in diameter. Mark the orbit with a line of ink or paint.

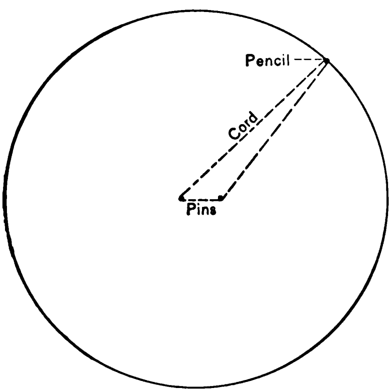


Fig. 8.—How to draw an ellipse.

Mark upon the ground a similar figure, using a doubled cord 94½ feet

long (one foot to a million miles). On this scale the sun will be nearly ten inches in diameter and the earth nearly one tenth of an inch. To realize the motion of the earth among the stars, walk around this path counterclockwise, with your face turned toward the center (the sun), and notice how the distant objects beyond and on a line with the center continually change. Walk around again with your face turned directly away from the center (the sun), and notice a similar procession of objects in the line of sight passing backwards or clockwise. On account of the brightness of the sunlight we can not see the stars in a line with the sun, but at midnight we can look directly overhead and see the stars which are on the opposite side of the earth from the sun. If we thus observed the zenith at midnight every night for one year, we should see a procession of stars apparently passing westward, and at the end of the year the same stars would be in the zenith at midnight as at the beginning of the year. It is not necessary to make these observations every night or at midnight. If we observe the position of any star or group of stars, as Orion, at the same hour, say 9 P.M., once a week or ten days, it will be found in a position farther to the west at each successive observation. Thus in watching the apparent annual westward march of the stars, we are really seeing the eastward movement of the earth around the sun.

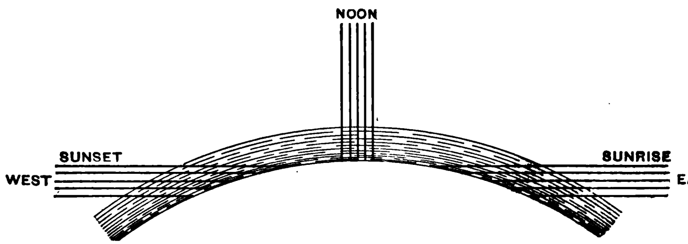


Fig. 9.

The Change of Seasons. — That the sun's rays have greater heating power at noon than at morning or evening is one of the most familiar facts in nature. This is due chiefly to two causes, shown in Fig. 9. At sunrise and sunset, the rays, being horizontal, pass through a greater thickness of air, which absorbs more of their energy, and they are spread over more surface, so that there is less

heat to the square mile. At noon, the rays, being more nearly vertical, pass through less air and cover less space, which makes the heat more intense.[1]

If the varying path of the sun in the heavens has been observed through the year (see p. 15), the facts are also familiar that in summer its path is longer and approaches nearer to the zenith than in winter. In June, the sun not only shines more directly in our latitude than in January, but also shines several hours longer each day. In spring and autumn, the angle of the rays and the length of daytime are intermediate. These changes are sufficient to account for the changing seasons. The causes of the variation in the path of the sun remain to be explained.

The Attitude of the Earth. — As the earth moves around the sun, its axis always points toward the Polestar, and is always inclined at an angle of about $66\frac{1}{2}°$ to the plane passing through the earth's orbit and the center of the sun, or about $23\frac{1}{2}°$ from a perpendicular to that plane. Thus the earth presents at different times of the year different faces to the sun, as is shown in Fig. 10.

Realistic Exercise. — It is not always easy to get a clear understanding of this subject from words and pictures, and resort should always be had to demonstration with some kind of apparatus, perhaps the simpler the better. Darken the room in which the orbit of the earth is marked upon the floor, place a lamp in the position of the sun, and carry a globe (almost any kind of a ball will answer) around the orbit counterclockwise, holding it in such a position that the axis stands at an angle of $66\frac{1}{2}°$ with the floor (the plane of the orbit), and the north end of it points directly north of the zenith. Observe that when the globe is in a position north of the lamp the northern hemisphere leans away from the lamp, the center of the lighted half is south of the equator, and the northern edge of the lighted half falls short of the north pole. When

[1] The idea sometimes met with that slanting rays heat less then direct rays because they strike with less force, is erroneous. Rays of heat and light have no force of impact and do not strike at all in the same sense as a ball or an arrow does.

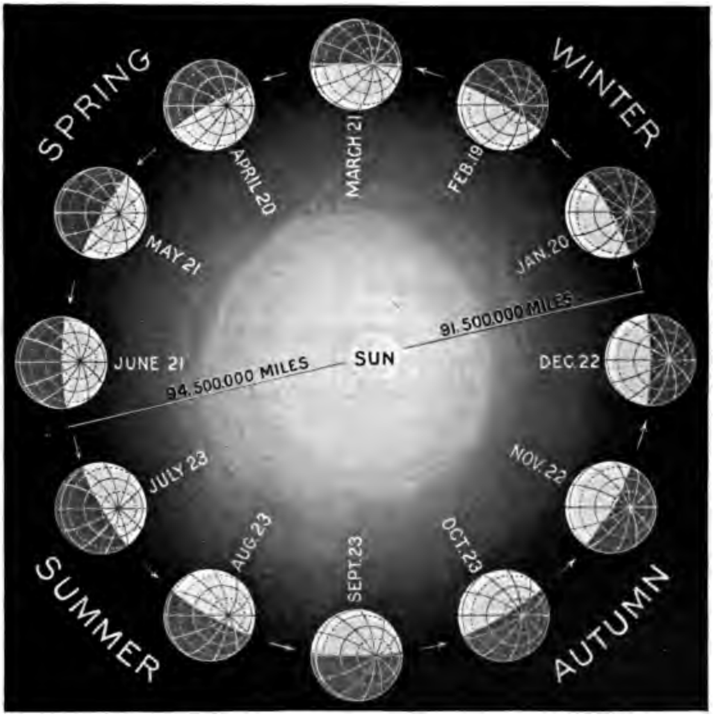


Fig. 10. — Position of the northern hemisphere throughout the year.

the globe is south of the lamp, the northern hemisphere leans toward the lamp, the center of the lighted half is north of the equator, and its northern edge reaches beyond the north pole. When the globe is east or west of the lamp, the northern hemisphere is still inclined, but neither toward nor away from the lamp, the center of the lighted half is at the equator, and its edge just reaches either pole. Observe that at the center of the lighted half the rays strike the surface of the globe perpendicularly, at other places more and more slantingly as the distance from the center increases, and at the edge of the lighted half the rays just graze the surface horizontally, or are tangent to it.

Results of the Earth's Attitude. — If the axis were perpendicular to the plane of the orbit, that plane would always be the same as the plane

of the equator, and the sun would always be vertically above some point on the equator. As it is, the sun is vertical at the equator at two opposite points in the earth's orbit, on September 23 and March 21. On June 21 the northern hemisphere is inclined toward the sun so that the vertical rays fall on the Tropic of Cancer, 23½° north of the equator, and the tangent rays reach the Arctic Circle 23½° beyond the north pole. On December 22 the northern hemisphere is inclined away from the sun so that the vertical rays fall on the Tropic of Capricorn, 23½° south of the equator, and the tangent rays reach the Arctic Circle 23½° short of the north pole. Where do the tangent rays reach in the southern hemisphere on June 21 and December 22?

This change of face presented to the sun is manifested to us in the varying daily path of the sun through the heavens, as it swings back and forth, north and south, once a year.

Realistic Exercise. — Admit a beam of direct sunlight through a hole in a curtain or shutter. Hold a book so that the beam strikes its surface perpendicularly; incline the book and observe the lighted spot grow larger and less bright as the angle increases. From Fig. 9 it is evident that on account of the curvature of the earth's surface the parallel rays of the sun must always strike perpendicularly at some spot and at all others more or less slantingly, and that the area covered by any given bundle of rays increases as their slant increases. Therefore as the daily path of the sun approaches the zenith its heating power increases, and as it recedes from the zenith decreases.

The Inequality of Day and Night. — Consult the almanac and find the length of the longest day and the shortest day in your latitude. If you can get an English almanac, find the same thing for London.

Figure 6 shows how the portion of the sun's path above the horizon varies with the seasons, and Fig. 10 shows why this is so. About December 22 much less than half the northern hemisphere is in the sunlight; hence the parallel of latitude or path of rotation of any given place, as New York or London, is more than half in darkness, and the time required to pass through the night is longer than that

required to pass through the day. In the southern hemisphere the reverse is true, and on June 21 the condition of each hemisphere is the reverse of that on December 22. At the equator the days and nights are always equal, but the inequality increases toward the poles. Thus the sun's long brush paints the earth with bands of heat which swing back and forth, following the march of the apparent path of the sun and bringing the change of seasons.

Equinoxes and Solstices. — The dates on which the sun is vertical over the equator and the days and nights are of equal length, March 21 and September 23, are called the Vernal and the Autumnal Equinox. The dates when the sun is vertical over the tropics, June 21 and December 22, are called the Summer and the Winter Solstice. The earth is nearest the sun on January 2 and farthest from it on July 3. It moves faster in that part of its orbit which is nearest the sun, hence the northern summer, from March 21 to September 23, is about six days longer than the northern winter.

Location upon a Sphere. — If we take a perfectly plain ball of any kind and mark a point upon it, we shall find it impossible to describe in any way the position of the point. If we spin the ball like a top upon the table or when suspended from a cord, and thus establish an axis, two poles, and an equator, the position of any point may then be determined and described by its distance from them.

Latitude. — The angular distance north or south from the equator is measured and expressed in degrees of latitude from 0° to 90°. If the earth were a perfect sphere, every degree of latitude would be $\frac{1}{360}$ of the circumference of the earth; but the polar diameter being twenty-six miles shorter than the equatorial diameter, the convexity of the earth grows gradually less from the equator to the poles, and a degree of latitude becomes $\frac{1}{360}$ of the circumference of a larger and larger circle. Latitude is the angle between the radius of curvature of the earth's surface at

any point and the plane of the equator. The degrees increase in length toward the poles (Fig. 11), according to the table on p. 25.

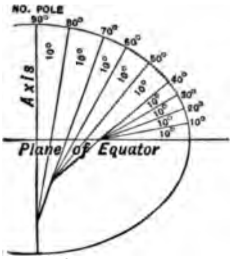


Fig. 11. — Degrees of latitude.

Realistic Exercise. — At the equator the Polestar appears just at the horizon, midway between the equator and the pole it is 45° above the horizon, and at the pole it is in the zenith. The altitude or angular distance of the Polestar above the horizon at any place is equal to the latitude of that place.

On March 21 and September 23 the sun is directly over the equator. Observe the noon altitude of the sun on either of these days and subtract it from 90°; the remainder is the latitude of the place.

Longitude. — It is evident that all places equally distant from the equator are situated upon a line parallel with the equator and have the same latitude; and it is necessary to

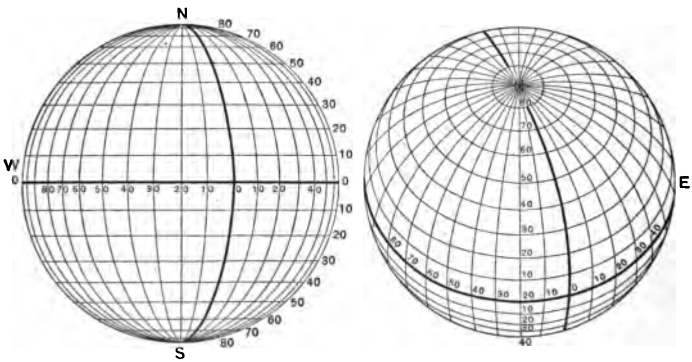


Fig. 12. — Parallels and meridians.

determine the position of each place upon its parallel of latitude. This is done by drawing lines called *meridians* from pole to pole at right angles to the parallels, and measuring the angular distance of the meridian passing through

each place from some prime meridian arbitrarily adopted. The civilized world generally has agreed to use the meridian of Greenwich Observatory near London as a prime meridian. Longitude is the angular distance between the plane of any meridian and the plane of the prime meridian, and is reckoned from 0° to 180° east and west of the prime meridian.

A degree of longitude upon the equator is $\frac{1}{360}$ of the circumference of the equator, but the circumference of successive parallels grows less toward the poles; therefore, the length of a degree of longitude decreases as the latitude increases, as given in the table below.

Longitude is generally determined by finding the difference in time between a given place and Greenwich. The sun apparently passes once around the earth, or over 360° of the earth's longitude, in twenty-four hours; hence it passes over 15° in one hour, or one degree in four minutes. Every ship captain carries a chronometer, which is only a very accurate clock, set at Greenwich time. By an observation of the sun the officer determines his own local time, and from the difference between that and his chronometer time his longitude is readily calculated.

When two places are connected by telegraph it furnishes a very convenient and accurate method of determining their difference in longitude. A signal sent from Greenwich at noon reaches St. Louis at about 6 A.M. St. Louis is therefore about 90° west longitude. A signal sent from St. Louis at noon reaches Denver a little after 11 A.M.; therefore Denver is nearly 15° west of St. Louis.

LENGTH OF ONE DEGREE IN STATUTE MILES

In Latitude	0°,	1° Latitude	= 68.704 mi.,	1° Longitude	= 69.172 mi.
"	10°,	"	= 68.725 "	"	= 68.129 "
"	20°,	"	= 68.786 "	"	= 65.026 "
"	30°,	"	= 68.879 "	"	= 59.956 "
"	40°,	"	= 68.993 "	"	= 53.063 "
"	50°,	"	= 69.115 "	"	= 44.552 "
"	60°,	"	= 69.230 "	"	= 34.674 "
"	70°,	"	= 69.324 "	"	= 23.729 "
"	80°,	"	= 69.386 "	"	= 12.051 "
"	90°,	"	= 69.407 "	"	= 00.000 "

CHAPTER II

STRUCTURE OF THE EARTH

The Geographic Spheres. — The earth may be naturally divided into four well-defined parts or spheres.

(1) **The Centrosphere** is the central core or interior mass of the earth. It comprises much the largest part of the earth's weight and volume, but is inaccessible to man.

(2) **The Rock Sphere** (*lithosphere*) is the solid crust of the earth, forming the land masses and the sea bottom.

Fig. 13. – Section of part of the earth

(3) **The Water Sphere** (*hydrosphere*) is the liquid shell of sea water which occupies the depressions in the crust and covers nearly three fourths of its surface.

(4) **The Atmosphere** is the gaseous shell of air which forms the outer layer of the earth, covering land and sea.

Occupying chiefly the outer surface of the crust, but also to some extent the sea and the lower portion of the atmosphere, are two other groups of geographical features which may be called spheres, but only in a figurative sense. *The Life Sphere* (*biosphere*) includes all living creatures, both plants and animals. *The Mind Sphere* (*psychosphere*) includes all those features and institutions which are the products of human intelligence, such as states, cities, roads, and factories.

The Science of Geography deals especially with the region of contact and interpenetration between the rock sphere, water sphere, and atmosphere, the home of plants, animals, and men. Its business is to describe and explain the distribution of all the features found there. While the special field of the geographer lies on what is commonly called the earth's surface, he avails himself of whatever is known concerning any part of the earth to assist him in explaining the distribution of surface features.

The Centrosphere.—We have no direct knowledge of the interior of the earth. The deepest boring yet made (at Schladebach, Germany) is only about six thousand feet deep, and the deepest natural cut (the Grand Canyon of the Colorado) is about the same depth, which is hardly proportional to a pin scratch through the varnish of a globe. Yet certain inferences may be drawn with great probability concerning the condition of the centrosphere.

The pressure within the centrosphere is very great. Every mass of matter in it sustains the weight of the column of rock above it, as the foundation of the Washington monument is under the pressure of the stones placed upon it. It is calculated that at the depth of one hundred and fifty miles the pressure is one million pounds per square inch, and at the earth's center thirty million pounds. Below a depth of eight miles the pressure is sufficient to crush the strongest materials; therefore, no open space or cavity can exist there.

The density of the centrosphere is much greater than that of the crust. The average density of the whole earth has been determined by various methods, and it is thus shown that the earth weighs 5.6 times as much as an equal globe of water. But the average density of the rocks forming the crust is only between 2.5 and 3. Therefore, the material composing the centrosphere must be, on the average, about twice as dense as the crust. The supposition that this material may

be composed largely of iron, gold, and other heavy metals, is not unreasonable.

The temperature of the centrosphere is very high. In wells, mines, and tunnels the temperature is always found to increase downward. The rate of increase is variable, but averages 1° for every fifty or sixty feet. It is probable that at great depths the temperature does not increase so rapidly, and that below one hundred and fifty miles the centrosphere has a nearly uniform temperature of about 7000° F.

The centrosphere may be liquid, or solid, or partly liquid and partly solid. If the temperature increases downward at the rate of 1° for every fifty or sixty feet, at a depth of fifty miles it is hot enough to melt any substance known upon the surface of the earth. The eruption of melted rock from volcanoes in many parts of the world has encouraged the belief that inside of a thin solid crust the earth is a liquid mass. But people who have held this opinion have failed to take into account the fact that pressure raises the melting point of most substances, and at some depth not very great the pressure may be sufficient to prevent the rock from melting, in spite of its high temperature.

The attraction of the sun and moon pulls the sea out of shape and produces a regular rise and fall of the water known as the tides. If the centrosphere were liquid, it would be drawn out of shape in the same way, and the crust would heave up and down as the surface of the sea does. There is no evidence of such a movement; on the contrary, Professor Darwin and Lord Kelvin have shown that the earth keeps its shape as rigidly as though it were a globe of solid steel. This would not be possible for an earth built on the plan of an egg — a thin shell filled with liquid. The jar of an earthquake in Japan is often felt in England, and the time which it occupies in passing through the earth indicates that it passes through a solid and not a liquid.

The crust of the earth is not stretched smoothly over it like the skin of an apple, but is very much wrinkled, folded, and crumpled, especially in mountainous regions. There is some difficulty in conceiving how the crust could become crumpled over a solid globe; but experiments have shown that under great pressure the most rigid solids, such as steel, act as if plastic and yield slowly to pressure like butter. Consequently the centrosphere, although solid, may act as if plastic, yielding enough to permit all the movements which have taken place in the crust.

Volcanic eruptions may be accounted for by supposing that the lava comes from cisterns of liquid rock of no great extent, or that the rock melts in certain places where the wrinkling of the crust partly relieves it from pressure. Some geologists have been led to suppose that between the solid crust and the solid core there is a shallow layer of liquid matter all around.

The condition of the centrosphere is necessarily shrouded in much uncertainty; but the theory which seems to account best for all the facts supposes the existence of

(1) A very large, dense, and hot core, solid because of the pressure upon it.

(2) A surrounding shallow layer of liquid or semi-liquid matter, upon which the solid crust or rock sphere floats.

So far as the structure of the earth is concerned, it may be roughly compared to a hot iron ball coated with tar and covered with wrinkled leather. Sir William Dawson compares the earth to a plum, peach, or cherry somewhat dried up; it has a large, hard stone or kernel, a thin pulp, and on the outside a thin skin; it has shrunk slightly, so as to produce wrinkles in the skin, and in some places the skin has cracked, allowing small quantities of the pulp to ooze out.

The Earth-crust; Mantle Rock. — It is a matter of common observation that the crust of the earth is made up of a variety of materials. This may be seen almost anywhere: in a plowed field, in an excavation for a cellar or ditch, in a cut made for a wagon road or railroad, in the banks of a stream, in a gravel pit or quarry. In lowlands and valleys, and on gentle slopes, the surface materials lie in a loose, incoherent mass, which may be removed with spade and pick. This loose and workable material is often called soil; but it is better to use that term for

only the upper layer of it, and to call the whole mass, however deep, *mantle rock*, because it overlies and covers the other rock. The common varieties of mantle rock are clay, sand, gravel, pebbles, and boulders. They are all fragments of older rocks which have been broken up, and wholly or partly pulverized and decomposed.

Clay is a soft, almost impalpable powder like flour, sticky and greasy when wet, and easily molded into any desired form.

Sand is a mass of loose, hard grains, usually of the mineral quartz. The grains may be coarse or fine, sharp or rounded, but sand is always recognizable by its harsh, gritty feel.

Gravel is composed of small stones, larger than sand grains. The stones may be angular or rounded, and of any color or composition, but are usually hard and smooth.

Pebbles and Boulders are large fragments of any kind of rock which have been broken off and moved from the parent bed.

Mixtures of clay, sand, gravel, and pebbles occur in all proportions. A mixture of sand and clay is commonly called *loam*; when it contains also a portion of decayed vegetable matter (*humus*) it forms a fertile soil.

Marl is a whitish mud found at the bottom of some lakes and ponds. It is a mixture of clay and lime derived largely from the decay of the shells of mussels, snails, and other animals.

Peat or *muck* is a black mud formed by the decay of vegetable matter under water. It sometimes accumulates in lakes and marshes to the depth of many feet.

Realistic Exercises. — Collect as many kinds of mantle rock as possible and examine them carefully. Note the feel, color, odor, and taste of clay, and its behavior when wet. Under a good microscope the powder of dry clay is seen to consist of minute, flat, translucent scales. Examine different specimens of sand with a hand magnifier, and note the size, shape, and color of the grains. Shake up loam or a mixture of sand and clay in a tall bottle of water and let it settle. The sand will go to the bottom very quickly, while the clay will settle slowly on top of the sand: it makes the water turbid or roily, and it may take twenty-four hours for all the clay to settle and leave the water clear.

Examine specimens of clean gravel: it may be necessary to wash

out the sand and clay in a stream of water. From a pint or quart of gravel pick out the smooth, rounded stones and count them; count the rough, angular stones, if any, and determine what per cent they are of the whole number. Try the hardness of each stone with the point of a knife and determine what per cent of them are soft, that is, easily scratched with a knife, and what per cent are hard, that is, scratched with difficulty or not at all. Bear in mind for future investigation the question, Why are most gravel stones hard and smooth?

Fig. 14.—Shale overlain by mantle rock.
(Near Terre Haute, Ind.)

Examine as many boulders as possible: note their size, shape, and hardness, and whether they are composed of only one kind of mineral or of several kinds. The shape may be *rounded*, without flat faces; *sub-angular*, with flat faces and rounded edges and corners; or *angular*, with sharp edges and corners.

Examine a specimen of marl and note the fragments of shell. In peat observe the fragments of roots, stems, and leaves.

Bed Rock. — If we dig or bore down far enough into the mantle rock, it will be found to be of moderate depth, and

to be everywhere underlain by *bed rock.* This is a solid, massive, continuous sheet of rock which extends indefinitely in every direction and requires the drill and hammer, or even the use of gunpowder or dynamite, for its removal. On mountains and in regions of steep slope the bed rock is very thinly covered or lies bare and exposed to the weather. A projection of bed rock through the mantle rock often occurs upon a hillside or cliff, and is called an *outcrop* or exposure. Bed rock is also likely to be exposed in the bed or along the banks of a stream. Over the greater part of the land surface bed rock is found to lie in distinct layers. A set of layers of one kind of rock is called a *stratum* (plural, *strata*). Shale, sandstone, conglomerate, and limestone are the only common kinds of stratified bed rock.

Fig. 15. — A sandstone cliff.
(Montgomery County, Ind.)

Shale or *mud rock* (Fig. 14) is nothing but compacted and hardened clay. It is soft and fine-grained, has the feel, odor, and taste of clay, splits easily into thin, irregular blocks, and is popularly, although wrongly, called "soapstone." It is usually of a gray or brown color, but may contain vegetable matter enough to make it black. The harder and more compact varieties of shale split into thin, regular leaves and are commonly, although wrongly, called *slate.*

Sandstone (Fig. 15) is composed of sand grains held together by some kind of cement. It may be fine- or coarse-grained; tough and

compact or loose and friable, so that it can be crumbled with the fingers. The colors vary from nearly white through gray and brown to dark red. The granular structure may be easily recognized by the harsh feel or the appearance under a magnifier. The most common cements in sandstone are clay, lime, silica, and iron, to which the red color is due. Grindstones and whetstones are made of fine and even-grained sandstone in which the cement is silica. The layers may be many feet in thickness or as thin as pasteboard. They often contain glistening grains of mica.

Fig. 16. — Fragment of conglomerate.

Conglomerate is cemented gravel and is often found in the lower part of a gravel bed. If the pebbles are rounded, it is called *pudding stone*; if angular, *breccia*.

Limestone (Figs. 17, 18), the most abundant of all rocks, is largely composed of the skeletons or shells of animals which lived in water. These may be microscopic, as in chalk, or easily recognizable as shells, corals, crinoid stems ("button molds"), or other forms. Limestone is of all colors and is not too hard to be scratched with a knife. A drop of cold dilute hydrochloric acid placed upon limestone dissolves it with foaming, due to the escape of gas. Some limestones are formed by the deposit of lime from solution in water, as the *stalactites* and *stalagmites* in caves, and the *tufa* around the mouths of some springs. Many limestones are composed of small rounded grains in appearance like fish eggs. This kind is called *concretionary* or *oölitic* limestone.

Shell. Tufa.

Fig. 17. — Specimens of limestone.

Bituminous coal, or *soft coal*, is a stratified bed rock formed by the consolidation of peat.

Aqueous or Sedimentary Rocks. — All the rocks thus far described, including both mantle and bed rocks, are composed of materials which, in most cases, have been removed from their original position and carried some distance by running water. When the current of a stream slackens its speed or enters the still water of a lake or the

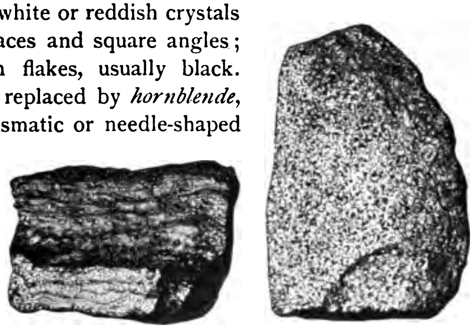
ocean, the mud, sand, and gravel which the stream has been carrying settle to the bottom. By this process the materials are deposited in nearly level layers or strata and are generally assorted so that each layer is composed chiefly of one kind of sediment. Hence all rocks thus formed are classed together as *aqueous*, *sedimentary*, or *stratified* rocks.

Fig. 18. — Limestone cliff.
(Near Madison, Ind.)

Igneous and Metamorphic Rocks. — If at any place we bore down through the mantle rock and through the layers of stratified bed rock, at a greater or less depth we strike bed rock which is not stratified and which owes its form and structure to the action of heat. In volcanic regions, melted rock has escaped in vast quantities through cracks in the crust, spread out over the stratified rocks, and cooled in the form of lava streams and sheets. It is often blown out of volcanoes in the form of lava dust, sand, or gravel. Such rock is called *eruptive* or *volcanic*. In many cases the melted rock has not succeeded in reaching the surface, but has forced itself into the cracks and between the layers of stratified rock and solidified there at considerable

depths. Such rock is called *intrusive*. All rocks which have cooled from a once molten condition are called *igneous*. Other rocks have not been melted, but have been more or less changed from their original fragmental and stratified form by heat and pressure, and hence are called *metamorphic* or altered rocks. Igneous and metamorphic rocks are distinguished from aqueous rocks by being often unstratified and made up, not of fragments, but mainly or wholly of crystals. The crystals may be too small to be seen by the naked eye, but they are often conspicuous from their shape and sparkling luster. Some igneous rocks are not granular or crystalline, but structureless like glass.

Granite is a common representative of a large family of igneous rocks, each member of which is composed of a mixture of two or more different minerals, rather coarsely crystallized and presenting a speckled or mottled appearance. Granite commonly consists of three minerals: (1) *quartz*, in glassy, lustrous grains too hard to be scratched with a knife; (2) *feldspar*, in white or reddish crystals which break with flat faces and square angles; (3) *mica*, in soft, thin flakes, usually black. The mice is sometimes replaced by *hornblende*, in greenish or black prismatic or needle-shaped crystals. A mixture of feldspar with hornblende or mica, but without quartz, is called *syenite*. If the minerals named above as forming granite are not thoroughly mixed, but occur in more or less regular bands, the rock is called *gneiss*. A mixture containing a large proportion of mica in coarse flakes, and therefore splitting easily, is called *mica schist*.



Gneiss. Granite.

Fig. 19. — Igneous rocks.

Basalt or *trap rock* is a common representative of a group of minutely crystalline or glassy igneous rocks which are usually of a greenish or black color.

Realistic Exercise. — Collect as many specimens of rock as possible, both stratified and unstratified. Almost anywhere north of the Ohio and Missouri rivers a gravel pit will furnish a hundred different kinds. Try first to separate the aqueous rocks from the igneous and metamorphic. The latter are the more difficult, and to make much progress in studying them a descriptive handbook with a few labeled specimens are necessary.[1]

CLASSIFICATION OF COMMON AND TYPICAL ROCKS

ORIGIN	CLASS	TEXTURE	BED ROCK CONSOLIDATED	MANTLE ROCK UNCONSOLIDATED
Aqueous Rocks Deposited by water or ice. Usually stratified.	Mechanical Sediments.	Fragmental.	Shale. Sandstone. Conglomerate.	Clay. Sand. Gravel.
	Chemical or Organic Sediments.	Crystalline, Compact.	Limestone. Bituminous Coal.	Marl. Peat.
Igneous Rocks Cooled from a melted state. Unstratified.	Eruptive or Volcanic. Cooled on the surface.	Compact or Crystalline. Glassy.	Basalt. Trap (Lava). Obsidian, Pumice.	
	Intrusive. Cooled below the surface.	Crystalline.	Granite. Syenite.	
			ROCK NAME	ORIGINAL FORM
Metamorphic Rocks Altered by heat and pressure.	Stratified.	Slaty. Compact. Crystalline. Glassy.	Slate. Quartzite. Marble. Anthracite Coal.	Shale. Sandstone. Limestone. Bituminous Coal.
	Unstratified.	Banded. Schistose.	Gneiss. Mica Schist.	Conglomerate or Granite. Shale or Granite.

[1] The Washington School Collection, furnished by E. E. Howell, Washington, D.C., is very good.

The Structure of the Earth-crust. — The crust of the earth, so far as accessible to us, consists of three general layers.

(1) On the outside, *mantle rock*, a layer of loose, unconsolidated, generally stratified fragments, nowhere more than a few hundred feet thick, and in many places entirely wanting.

(2) A layer of stratified and consolidated rock fragments, perhaps averaging five or ten miles in thickness. In mountainous regions it has been extensively warped, crumpled, and broken, and in some localities removed by erosion.

(3) A fundamental, unstratified layer of unknown thickness, which has cooled and crystallized from a previously molten condition. It has also extensively penetrated into and through the other layers, and has thus become surface rock in some places.

CHAPTER III

THE FACE OF THE EARTH

"If an observer from the depths of celestial space could observe the surface of our globe as it would present itself to him in the course of a daily rotation, the most striking feature would be the gradual narrowing of the continents toward the south." — SUESS.

The large and striking features of the face of the earth are due to the fact that the surface of the earth-crust is slightly irregular, and the waters of the sea have accumulated in its depressions. Those portions of the crust which project above the water level form the land masses, great and small, continents and islands. The shore line of the sea is the boundary between two strongly contrasted regions: the land with its varied surface and products, and the unbroken expanse of the ocean.

Seventy-two per cent of the surface of the solid earth seems to be hidden from observation under a barren blanket of water. But apparatus has been invented by which we may feel down through the water and gain considerable knowledge of the solid crust beneath; so that we can now represent to our imagination the main features of the earth as they would appear without water in the sea. On the relief map of the world, pp. 40, 41, the most prominent feature is the crookedness of the lines which mark the different levels and the consequent irregularity of the areas which they inclose. The largest tracts of approximately uniform level occur on the sea bottom between six thousand and eighteen thousand feet below the surface (medium shades of blue). Figure 20 shows the proportions of the

earth-crust which lie at the various levels. More than half (57 per cent) of its surface lies under water six thousand feet or more in depth. This is called the *area of depression* or deep sea floor. The dry land (red and white) rests upon a block or foundation (lightest blue) a little larger than itself, which rises rather steeply from the sea floor. This continental block, comprising the land and the narrow belt of sea bottom around it, over which the water is less than six thousand feet deep, is called the *area of elevation.*

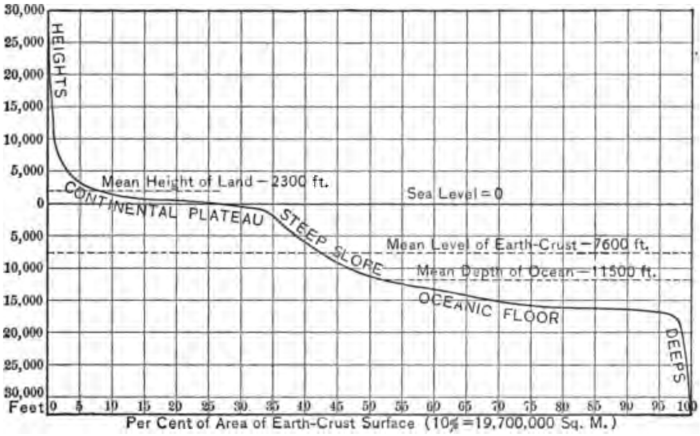
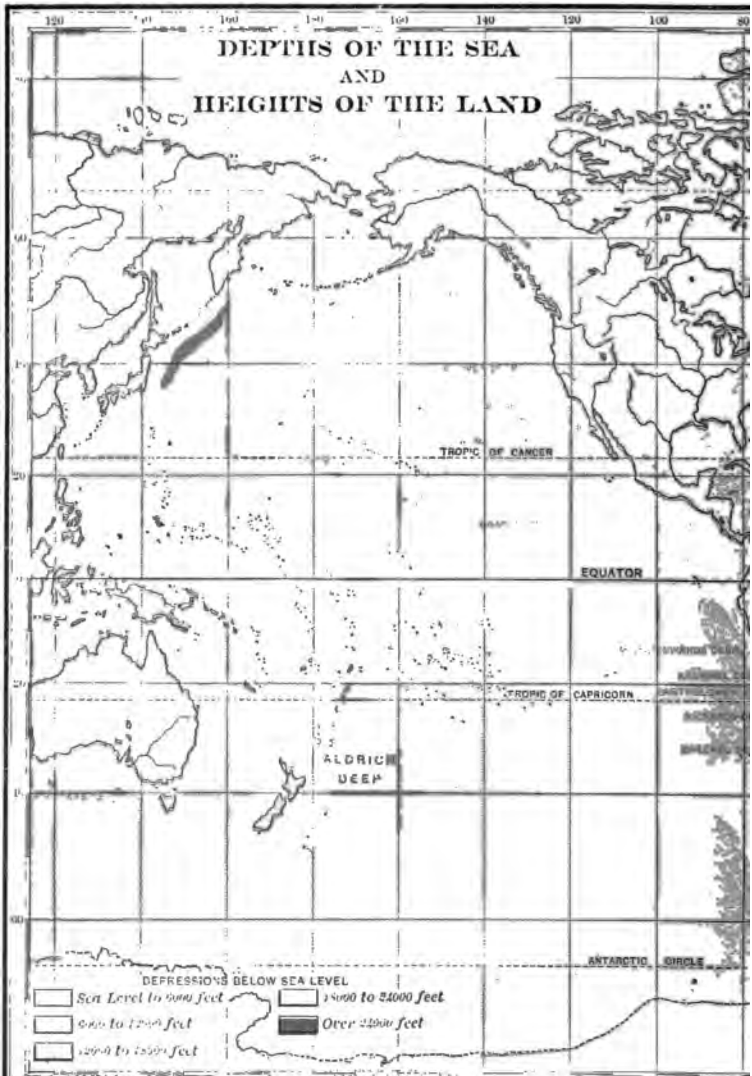


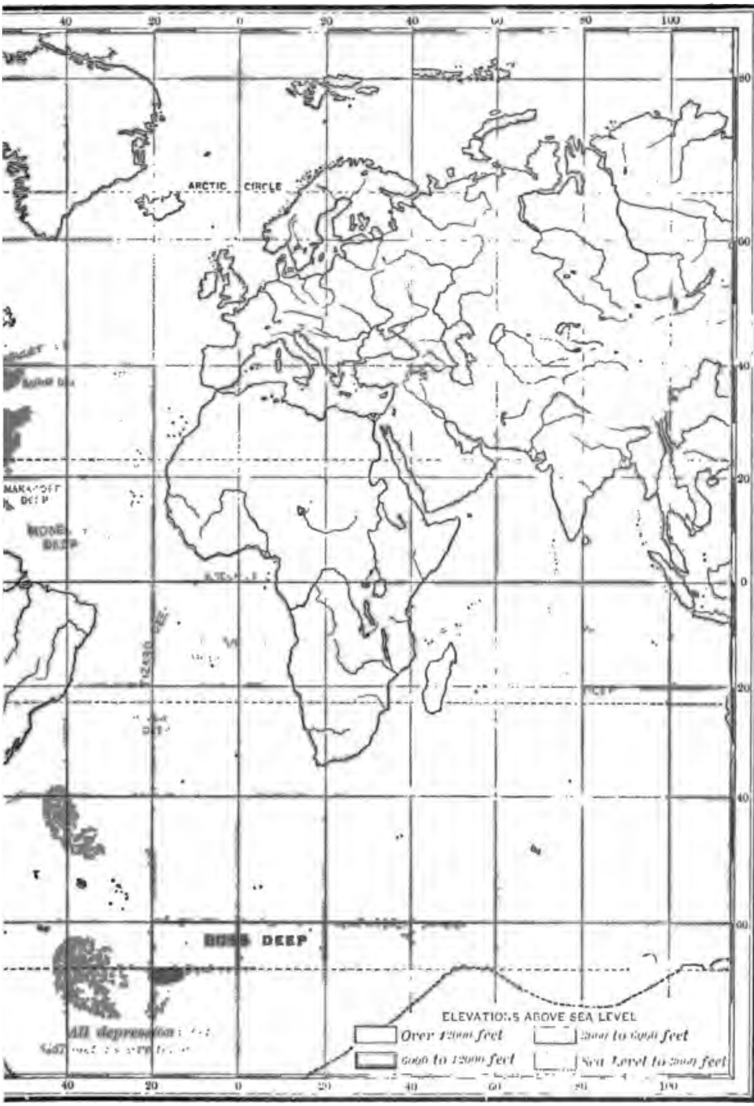
Fig. 20. – Generalized profile of the earth-crust.
(Hypsographic curve — after Wagner.)

Realistic Exercise. — Upon a hollow rubber ball five or six inches in diameter mark the poles and equator. Draw meridians and parallels 30° apart: using these as guides, mark the outline of the continental block, including within it the Gulf of Mexico, Caribbean Sea, Mediterranean Sea, Red Sea, the seas between Australia and Asia, and the Arctic Ocean. Cut the ball along the outline marked: one portion thus made will have the form of the area of elevation (the Arctic Ocean being at the center), and the other portion the form of the area of depression.

The Plan of the Earth. — The continental block surrounds the Arctic depression at a distance of about 20°



DEPTHS OF THE SEA
AND
HEIGHTS OF THE LAND
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ALDRICH
DEEP
ANTARCTIC CIRCLE
DEPRESSIONS BELOW SEA LEVEL
Sea Level to
feet
Over
feet


ARCTIC CIRCLE
ROSS DEEP
ELEVATIONS ABOVE SEA LEVEL

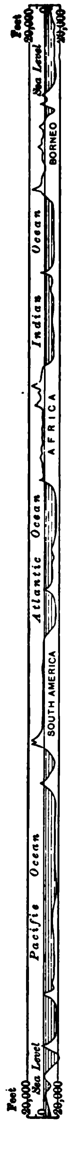


Fig. 21. — Profile along the equator.

from the north pole, and extends thence southward in three great arms. The longest arm is occupied by North and South America, a land mass which extends to 56° south latitude. The second arm is occupied by Europe-Africa, which ends at 35° south, and the third arm by Asia-Australia, which ends at about 40° south. The south polar regions are probably occupied by land, which projects in a few places a little beyond the Antarctic Circle, but north of this land the sea forms a belt around the globe, from about 10° to 30° in width, and sends northward three great arms which interlock with the arms of the land. The longest arm, the Atlantic Ocean, lies between the Americas and Europe-Africa, and is wide open at both extremities, forming a channel of communication between the two polar regions. The broadest arm, the Pacific Ocean, lies between the Americas and Asia-Australia. It is nearly closed at latitude 65° north. The third arm, the Indian Ocean, lies between Africa and Australia, and extends only to about 25° north latitude.

In this plan there are several striking peculiarities. (1) There is a large excess of water in the southern hemisphere. (2) Each of the three continental arms is more or less broken by deep inlets of the sea which serve to separate them naturally into grand divisions of the land. The American arm is thus broken at 10° north, the Europe-African at 35° north, and the Asia-Australian near the equator. (3) Most of the resulting land masses are triangular, with bases to the north, and tapering points toward the south. (4) The great land masses and ocean basins are set over against each other on opposite sides of the globe. Europe-Africa is opposite the Pacific, Asia-Australia opposite the Atlantic, and North America opposite the Indian, while South

America forms an exception in being opposite to the island region of the western Pacific. This antipodal arrangement of land and water has led some geographers to think that the earth is a spheroid slightly flattened on four sides, which determine the positions of the Arctic, Atlantic, Pacific, and Indian depressions, while the land masses, including the Antarctic continent, occupy the projecting edges and corners.

The Region of Depression. — More than three fourths of the sea floor (78 per cent) lies between 6000 and 18,000 feet below sea level. Its generally smooth surface is broken by a few narrow ridges which support groups or chains of islands, and by valleys or holes (colored darkest blue on the map), called *deeps*, a few of which exceed 24,000 feet in depth. The average depth of the sea is about 11,500 feet, or nearly 2⅕ miles. The greatest depth yet found is about 31,600 feet, near the Ladrone Islands in the western Pacific.

The Region of Elevation. — From the deep sea floor the continental block rises in most places rather steeply, so that its sides, comprising the region between 600 and 6000 feet below the sea level, form only 10 per cent of the area under water. Its upper surface is but slightly elevated, nine tenths of the land being less than 6000 feet above sea level.

Much ingenuity has been expended in the effort to discover some unity of plan in the relief of the several grand divisions, but without much success. Continents do not take the form of raised domes plunging steeply on all sides toward the sea; neither is there a central backbone of high land, a feature very prominent in large islands; nor are marginal highlands with a central depression between them the common rule. South America is bordered on the western side by the narrow wall of the Andes Mountains. In North America the two parallel systems of the Rocky Mountains and the Sierra Nevada-Cascade form a double barrier. The southeastern and southern parts of Asia are occupied by an irregular patchwork of lofty plateaus and mountains, which are prolonged through southern Europe to the Atlantic. In Africa and Australia the principal highlands lie along their eastern

sides. The only general plan of continental relief consists in the occurrence of an elevated margin next to the Pacific and Indian oceans, and of extensive lowlands next to the Atlantic and Arctic oceans.

The Coast Shelf. — The gentle slope of the lowlands often extends out to sea, forming a wide submerged shelf between the shore and the boundary of the steep slope of the continental block. Along a great part of the Atlantic coast the thin edge of the sea thus transgresses upon the land. On the other hand, the steep slope of the highlands near the Pacific coast usually continues under water, and the sides of the continental block plunge abruptly downward to the deep sea floor. The unbroken descent from the summit of the Andes to the sea floor amounts in some places to a fall of 42,000 feet in 80 miles. The slopes of the Gulf of Guinea are in some places as much as 2000 feet per mile.

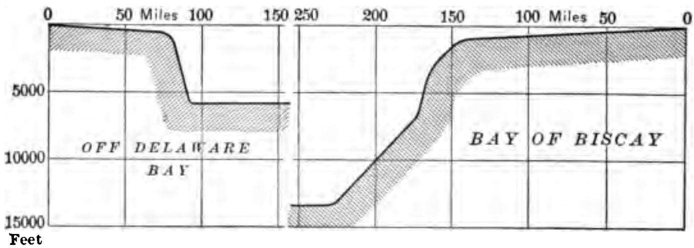


Fig. 22. — Profiles of coast shelves.

Irregularity of Land Surface. — The surface of the land is characterized by general roughness and irregularity, in contrast with the comparative smoothness of the sea floor. A profile of the land almost anywhere, drawn upon a scale large enough to show the smaller features, appears somewhat jagged, and in elevated regions it may resemble the teeth of a saw.

An examination of continental relief in detail reveals the presence of numerous inclosed basins nearly or wholly surrounded by mountains, especially in the central regions of Asia-Europe and Africa, and in western North America. As much as one fifth of the whole land surface is so inclosed as to have no outlet for drainage to the sea.

A few of these depressions in the land lie below sea level; of these the basin of the Caspian Sea is the largest and that of the Dead Sea the lowest.

More than one fourth (26.7 per cent) of the land surface of the globe lies between sea level and 600 feet, and nearly three fourths (73.7 per cent) below 3000 feet. The greatest height yet measured is Mount Everest in the Himalayas, 29,000 feet. The average elevation of the land is approximately 2300 feet, or a little less than half a mile.

Characteristics of the Grand Divisions. — In Europe more than half the surface (54 per cent) is less than 600 feet above the sea and only one tenth more than 6000 feet. It is the least elevated of all the grand divisions and is characterized by extensive low plains. Of all the grand divisions Africa has the smallest part (12.5 per cent) of its surface below 600 feet. It is characterized by extensive plateaus. Australia resembles Africa, but its elevation as well as its area is much less. Asia is distinguished by the height and massiveness of its mountain chains, which give it the greatest absolute height, 29,000 feet, and the greatest average height, 2884 feet. Thirty-eight per cent of it lies above 3000 feet. The Americas exhibit all the great relief forms, low plains, high plateaus, and mountain chains, without marked predominance of any. Their long north and south mountain systems are not continuous, but are separated in Central America by a system now partly submerged, but reappearing eastward through the West Indies.

Islands. — All the large islands except Madagascar and New Zealand, and many small ones, stand upon the continental block and seem to be the tops of peaks or ridges rising from its partly submerged surface. Oceanic islands rise from the region of depression and are of volcanic origin.

Comparative Smoothness of the Crust Surface. — In comparison with the size of the earth the irregularities of the crust are trifling. The lowest point known is a little over 31,000 feet below sea level and the highest point is 29,000 feet above sea level, so that the *range of relief* or vertical distance between them is only about 60,000 feet, $11\frac{1}{3}$ miles, or $\frac{1}{700}$ of the earth's diameter. Upon a globe 7 feet in diameter the range of relief proportional to that of the earth would be one eighth inch, which is considerably less in proportion than that of the roughness of the skin of an orange. If the elevations of the crust were used to fill the depressions and the whole surface were graded to one level, that surface would be 1.44 miles below the present sea level and would be covered with water 1.56 miles deep.

Sea and Land. — The sea itself, with an average depth of about $2\frac{1}{5}$ miles, is only a thin skin upon the globe which, like a shallow pool upon a sidewalk after a rain, serves to mark the outlines of a depression which would be otherwise scarcely noticeable; yet its volume is nearly thirteen times as great as that of the land above water. The position of the water surface or sea level determines the most important boundaries of the world. From it all heights and depths are measured, and by it all coast lines are fixed. A slight rise of sea level would submerge large areas of land and change entirely the outlines of continents; while a lowering of six thousand feet in its level would not materially change the outline of the continents, but would unite them into a single mass.

Causes of Relief.—The causes of irregularity in the surface of the earth-crust are not fully understood. This problem has been the subject of much study and speculation, and many hypotheses have been proposed to account for the depression of the deep sea floor and the elevation of the continental block.

Diastrophism. — The upper layers of the earth-crust on land are composed largely of sedimentary rocks, such as are now forming on the sea bottom near shore, and they contain the fossil remains of animals

which live only in shallow sea water. Hence we feel sure that nearly all the present land surface was once covered by the sea and has been raised from that position to its present elevation. The sedimentary strata have not only been raised bodily hundreds or thousands of feet, but they have also been broken, tilted, folded, crumpled, and crushed together in a manner which shows that they have been subjected to enormous horizontal pressure (see pp. 178, 192). The movements of elevation, depression, fracture, and dislocation are still in progress. Marks placed upon the rocks along the coast of Sweden many years ago show that the land is slowly rising, in some places three or four feet in a century. Buildings erected three or four hundred years ago on the west coast of Greenland are now under the sea. Buried stumps of trees on the coast plain of New Jersey furnish evidence that a slow sinking is in progress there. A Spanish magazine built near the mouth of the Mississippi about two hundred and thirty years ago is now more than ten feet under water. During an earthquake in 1822 the coast of Chile was suddenly raised two or three feet, and again an equal distance in 1835.

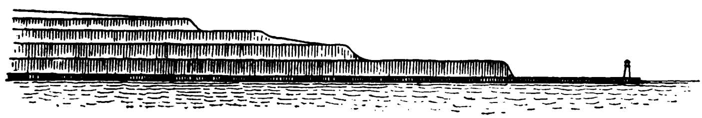


Fig. 23. — Cape Maysi, Cuba.

The coast of Cuba presents a series of raised benches which were cut by the waves when the land stood at lower levels than now. Any solution of the problem of the causes of *diastrophism*, or movement in the earth-crust, must account for the elevation of great continental areas and for the crumpling and breaking of the strata.

Isostasy. — It is thought by many geologists that the earth-crust under the ocean is denser and heavier than it is under the land, and that in consequence the sea floor sinks more deeply into the underlying centrosphere while the continental block is floated higher above it.

Realistic Exercises. — Float two blocks of wood of the same size and shape, one of oak and the other of pine, in a vessel of water, and note the different heights of their upper surfaces above the surface of the water.

Fill a U-shaped glass tube nearly half full of water. Pour oil into one arm and note the different levels at which the liquids stand. The shorter column of relatively heavy water balances the longer column of relatively light oil and holds its surface up to a higher level.

Several lines of evidence seem to indicate that the material composing the great plateaus and mountain ranges of the world is actually lighter than the average of the earth-crust. These regions are probably not held up at their high level by the rigid support of the surrounding parts of the crust, as the roof of a building is supported by the walls, but they are pushed up by the heavier masses of the sea floor, the pressure of which is transmitted in every direction, as if through a liquid or plastic layer beneath the crust. This condition of equal balance in the different parts of the earth has been called by Dutton *isostasy*.

Contraction. — The wrinkling and folding of the earth-crust has long been accounted for in another way. It seems certain that the earth was once much hotter than it is now, and that it is constantly radiating heat into the cooler space around it as a hot stone or iron radiates heat in a cold day. If the globe has been cooling, it must also have been contracting or growing smaller. The heat of the sun keeps the crust at a nearly constant temperature, but the centrosphere has kept on cooling and contracting until the crust has become too big for it and is compelled to fold and wrinkle by its own weight. The wrinkled skin of a withered peach or a cold baked apple is an example of a similar change.

Realistic Exercise. — Inflate a rubber toy balloon with air, cover it with a thin layer of flour paste, and rotate it in flour until a smooth dry coating is formed an eighth of an inch thick. Attach to it by a glass connector a rubber tube provided with a pinchcock. Immerse the end of the tube in water, and let the air escape from the balloon a few bubbles at a time. As the balloon contracts, the coating of paste will become folded and wrinkled in a manner quite similar to the folding of the earth-crust.

The hypothesis of isostasy, or balancing weights, seems best to account for the great regional elevations and depressions (continents and ocean basins), and the hypothesis of cooling and contraction best to account for such smaller features as mountain ranges.

The Representation of Relief. — The facts of geography are most conveniently expressed by the use of maps. The fundamental idea of a map is a drawing which shows *upon a horizontal plane* the location, direction, distance, and area of the features of the earth's surface as they are distributed. A plan of a house showing the arrangement, shape, and

size of the rooms, doors, windows, etc., and perhaps the location of pieces of furniture, is an example of a simple map. More complex maps may be made not only to show arrangement "on the flat," but also to indicate the "elevation" or relief of the surface. The map on pp. 40, 41, makes use of a common device for showing relief. The areas of different elevations are printed in different colors, various shades of blue being used for the sea floor, and shades of red for the land. Each boundary line of a color or shade is level or everywhere at the same distance above or below the sea level, measured vertically. These lines of equal elevation upon a map are called *contour lines* or simply *contours*.

The lightest shade of red shows all the land between sea level and three thousand feet above, but does not show where the land is just one hundred or twenty-nine hundred feet. The uncolored area shows all the land above twelve thousand feet, but does not show just how much above that level any point is. The boundary lines between the different colors or shades indicate exactly the elevation of the places through which they pass. The line between the red and the blue is the coast line and is everywhere at sea level, the line between the two lightest shades of blue is everywhere exactly six thousand feet below sea level, and the line around the outside margin of the darkest red is everywhere exactly six thousand feet above sea level.

By drawing contour lines at sufficiently small intervals relief may be indicated with any desired degree of precision. When contour lines are drawn at small intervals the spaces between them are frequently left uncolored.

Figure 24 shows a sketch or picture of a landscape and Fig. 25 a contoured map of the same region. In the foreground is a portion of the sea, the shore line of which forms the basal or zero contour. Contours are drawn upon the map at intervals of fifty feet *measured vertically* from the sea level, and they mark the lines where the seashore would be if the sea should rise fifty, one hundred, etc., feet. Where the slope is steep, one would have to travel only a short distance to rise fifty feet; hence the contours are close together. Where the slope is gentle, one would have to travel far to rise fifty feet; hence the contours

are farther apart. By shortening the contour interval to five or ten feet, as may be done upon a large-scale map, the elevation of every point may be shown very precisely. For showing exact elevation no device is equal to the contoured map; but it has the disadvantage of not being *graphic*, that is, of not being understood by everybody at a glance.

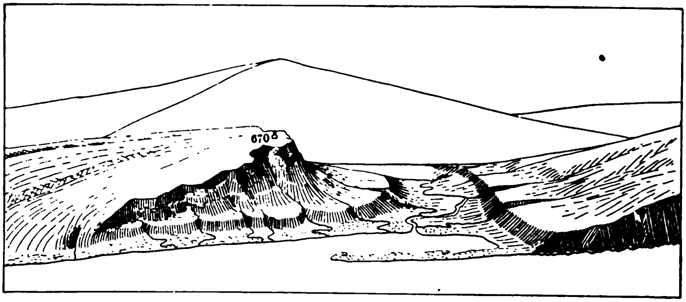


Fig. 24.

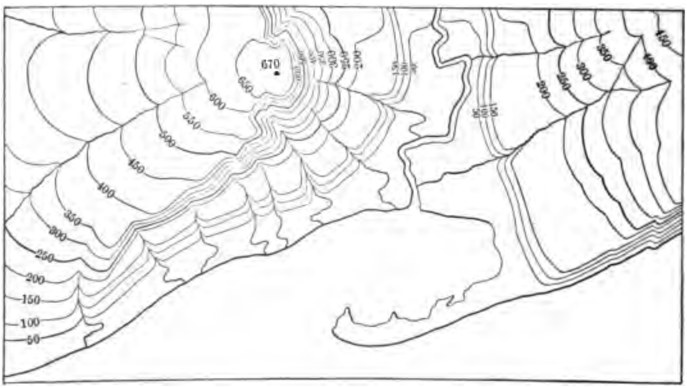


Fig. 25.

One must learn to interpret such a map before he is able to form a mental picture of the region shown.

Realistic Exercise. — Upon a table or floor make a clay model of a simple hill with both steep and gentle slopes. Lay a block of wood one inch thick beside it: with a pointed stick make a mark upon the side of the clay hill all around at the height of the upper surface of the block,

which should be moved around to guide the stick. Lay another block an inch thick upon the first and make another mark around the hill two inches above the table. Continue to add blocks until the top of the hill is reached. Each mark upon the hill will be one inch above or below the next, and will indicate exactly the height, above the table or floor, of the points through which it passes. Measure the horizontal distance between the marks upon the gentle and the steep slope. Now look down upon the hill from some distance above, and draw upon paper the lines as they appear from that point of view. The drawing will be a contoured map of the hill in which the contour interval is one inch.

Fig. 26.

Fig. 27.

A very common device for showing relief upon a map is the use of *hachures*, or fine lines running up and down the slopes, and so drawn as to show the steepness of the slope by the depth of shading. Hachured maps may be made very graphic and almost equal to a picture. Figures 26 and 27 show the relation between hachured and contoured maps of the same area. A combination of the two is the best possible method of showing relief upon a map.

Models are miniature reproductions of portions of the earth's surface in sand, clay, paper, plaster, or other material (see p. 393). They are often called relief maps. The vertical heights are usually exaggerated in order to show small details. This exaggeration is sometimes excessive, the elevations being made forty to one hundred times as

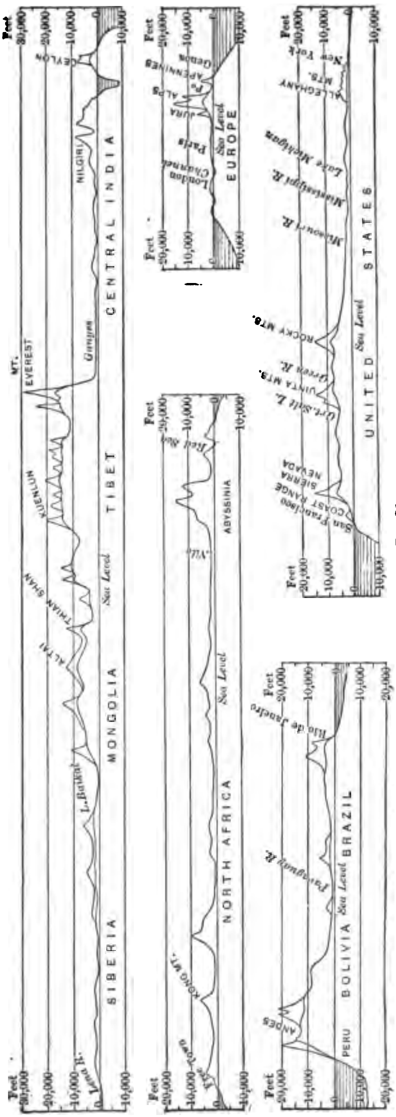


Fig. 28. — Profiles.

high as they ought to be in proportion to the widths shown. Thus all slopes become so steep and the forms of mountains and other features so unnatural as to render the model worse than useless because it teaches more error than truth. A good model, in which the heights are not exaggerated more than ten times, is generally the best representation of relief. Pictures of models are very good substitutes for the models themselves, but are subject to the same restrictions in regard to exaggeration of heights.

A *profile* shows the elevations and depressions of surface along any given line, which may be straight or crooked. It has two scales, the horizontal and the vertical. The latter is generally exaggerated, and often greatly so.

The student should

notice the amount of exaggeration in a model or a profile, and guard against the erroneous impression which it would otherwise give him.

The *stereogram*, or block picture, is a combination of model and section, and may be used very effectively to show the relation of relief and structure. See Fig. 154.

The Earth as the Home of Plants, Animals, and Men. — Life forms as we know them — plants, animals, and men — are able to live and flourish upon the earth because they have become adapted to a multitude of conditions which probably do not exist in the same combination upon any other planet. The most important conditions which make the earth habitable are dependent upon its position, form, attitude, motions, size, structure, and plan.

The position of the earth — its distance from the sun — determines the amount of heat which it receives. This is sufficient to maintain at all places upon the face of the earth a temperature which never falls lower than about 120° below the freezing point of water (−88° F.), and never rises higher than about 120° above the freezing point (152° F.). This makes it possible for large quantities of water to exist in each of three forms, — solid ice, liquid water, and gaseous vapor.

The form of the earth determines the angle at which the nearly parallel rays of the sun strike its face at different latitudes, and consequently the amount of heat received per square mile. This gives a variety of temperatures ranging from the torrid to the frigid.

The attitude of the earth, or the inclination of its axis, in combination with its daily and yearly motions, determines a change of seasons, or variation of temperature, at all latitudes, and prevents both the uniformity which would exist if the earth's axis were perpendicular to the plane

of its orbit, and the excessive variation which would result if the axis were nearly parallel to that plane.

The revolution of the earth around the sun at a nearly uniform speed in an orbit which is nearly circular brings about the regular succession of seasons and years, each of which is of moderate length. The succession of warm and cool, or wet and dry, seasons gives to plants and animals alternating periods of comparative rest and activity.

The rotation of the earth upon its axis exposes the greater part of its face to alternations of heat and cold, light and darkness, at short intervals, and imposes upon living beings correspondingly short and frequent periods of rest and activity. It also enables man to look out at night into space, see the moon and stars, and learn something of the universe of which the planet earth forms an insignificant part.

The size and density of the earth determine its mass, or weight, and consequently the force of gravity. The attraction of the solid earth is sufficient to prevent the atmosphere from escaping into space and to give it such composition and density as to support plant and animal life. The attraction of the earth also determines the weight of every object upon its face, and the strength or rigidity of plants and the muscular power of animals are nicely adapted to support or to move their own and other weights.

The structure of the earth gives a firm crust for the support of all creatures which live upon the land, while the outer layer of pulverized mantle rock furnishes a permeable bed for the roots of plants and a storehouse of available food. Even the centrosphere contributes to the food supply; for the masses of igneous rock which have escaped from it gradually crumble into mantle rock and are converted into fertile soil. The presence of large fluid

masses of water and of air makes it possible for extensive systems of currents to circulate in the atmosphere, in the sea, and on the surface of the land. Thus the materials of the earth are kept in motion and its face is made to undergo perpetual change. It is this which keeps the earth a living planet as distinguished from a dead one like the moon, and contributes to that variety and beauty of sky and landscape which make it a pleasant home for man.

The sea is the home of millions of living forms, and it furnishes water for all those which live upon the land. The atmosphere not only rests upon the land, but penetrates to the bottom of the sea and supplies all creatures with the breath of life. From it plants obtain the carbon which forms the greater part of their own substance, the food of animals, and the material of fuel. It absorbs and retains the heat of the sun, tempering its intensity by day and preventing its too rapid escape by night. Currents of air carry the water-vapor from the sea and distribute it as rain and snow over the land. The air and the water which falls from it attack the solid crust of the earth and break it up into mantle rock.

The plan of the earth presents a vast expanse of water broken at intervals by large and small masses of land. While the land masses predominate in the northern hemisphere, their longer axes extend north and south through so many degrees of latitude as to traverse all the zones of climate. This variety is made still greater by diversities of elevation, relief, and distance from the sea. The number and variety of living forms probably decrease from near sea level downward to the deep sea floor and upward to the mountain tops, but the great expanse of sea surface and the low average elevation of the land make a very large proportion of the face of the earth available for a

dense population of some kind. The arrangement and relief of the land masses are such that the moisture evaporated from the sea is very unevenly distributed over them. Some portions receive an excess of rainfall, while extensive areas in every continent are so dry as to be very unfavorable to the existence of life.

Land plants and animals are generally unable to cross oceans, deserts, or mountains, and the presence of these natural barriers has largely controlled the migration and distribution of man himself. If, from the whole face of the earth, those portions are deducted which are either too high, too low, too hot, too cold, too wet, or too dry, there remains not more than one tenth part which is suitable for the home of a dense population of civilized men. The infinite variety of situation, relief, soil, and climate has brought about a corresponding variety of living forms, each adapted to the peculiar set of conditions under which it lives. Probably no large part of the sea or land is entirely devoid of life; but the sphere of life is strictly confined to the thin shell of the earth where land, water, and air intermingle. Not far below it lies the fervent heat of the centrosphere, and not far above it the intense cold of stellar space.

Reference Books. — For a list of reference books on subjects included in Book I, see Appendix IV, especially pp. 413, 414.

BOOK II. THE LAND

The hills are shadows, and they flow
From form to form, and nothing stands:
They melt like mist, the solid lands,
Like clouds they shape themselves and go.

— TENNYSON'S *In Memoriam.*

CHAPTER IV

EROSION

Weathering. — The contrast between the roughness of the land surface and the smoothness of the sea floor is due to the fact that the land is exposed to the action of the atmosphere, while the sea floor is protected from it. The direct action of the air and the weather upon the earth-crust is a complex process called *weathering*, accomplished and assisted by various agents. Its general result is to break up and crumble the surface of the land.

(1) *Oxygen* is an active chemical agent which causes rocks to decay and crumble by a process like the rusting of iron. *Carbon dioxide* attacks igneous rocks and converts them into materials from which stratified rocks are formed.

(2) *Rainwater* dissolves the cement present in many rocks, which in consequence fall to pieces. It also mechanically removes and washes away loose particles.

(3) *Frost* is one of the most efficient agents concerned in breaking up rock masses. When water freezes in the pores and crevices of rocks, it expands, and thus enlarges the cracks or makes new ones. When the morning sun, after a frosty night, strikes against a cliff, there is often a

continuous shower of rock fragments which have been loosened by the freezing and thawing. At high altitudes, where changes of temperature are frequent and severe, mountain peaks are rapidly broken down by this process.

(4) *Changes of temperature* which do not include freezing and thawing act in a similar manner. When rock at any temperature is warmed it expands, and when cooled it con-

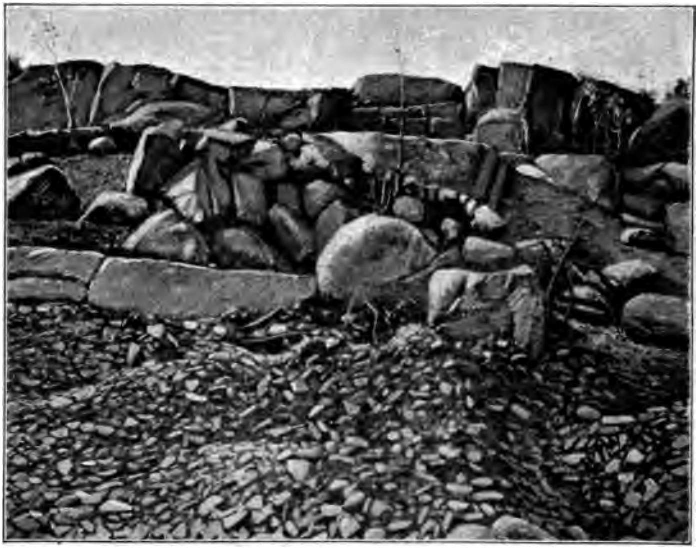


Fig. 29. — Weathered granite.
(Near St. Cloud, Minn.)

tracts. Repeated expansion and contraction tends to break it up, especially to scale off thin sheets from the surface. This process is often used to break in pieces large boulders. They are first heated by a fire, and then suddenly cooled by throwing water upon them.

(5) *Gravity* is continually pulling every mass of rock downward, and if the rock mass is insufficiently supported

it breaks off by its own weight. Gravity is not a part of the atmosphere, but in all processes of weathering it is a silent partner which never forgets or lets go for a moment.

(6) *Wind*, by its own force, but more efficiently by blowing sand against rock, wears it away. Even the hardest materials, as steel and glass, are rapidly carved and eroded by wind-blown sand.

(7) *Plants and animals*, although not a part of the atmosphere or factors of weather, may be included among the agents of rock disintegration. The roots of plants penetrate crevices in the rock and by their growth force the sides farther apart. Decaying vegetation furnishes an acid which increases the solvent power of water. Various burrowing and boring animals accomplish some less important work in rock destruction.

Fig. 30. — Cliffs eroded by wind and sand.
(Near Prescott, Ariz.)

By the action of all these agents large masses of rock are disintegrated and reduced to smaller and smaller fragments. Some rocks are also chemically decomposed and changed into other minerals. Weathering is the process by which massive bed rocks are converted into mantle rocks, and its products are clay, sand, gravel, pebbles, and boulders.

Of these, only clay is a product of chemical decomposition and bears little resemblance to the original igneous or metamorphic rock from

which it was produced. The other kinds of mantle rock are clearly recognizable as fragments of larger masses. Weathering is not confined to the surface of the earth-crust, but extends as far down as air and water penetrate. It is most active in the zone between the surface and the level of permanent ground-water. The bed rock is sometimes found to be broken up or "rotten" to the depth of one hundred feet or more. In some places the mantle rock lies undisturbed in the position where it was formed, and the transition from soil to bed rock is so gradual that it is impossible to tell where one ends and the other begins. (See Fig. 14.) More frequently the loose fragments have been removed some distance and deposited in another place. Mantle rock in place is called *residual soil*, while that which has been transported is often called *drift*, — wind, glacial, or stream drift, according to the agent of transportation.

Weathering is most rapid and extensive (1) in regions of heavy rainfall, (2) at high altitudes, where changes of temperature, especially freezing and thawing, are frequent, (3) on steep slopes, where gravity acts most efficiently and the mantle rock promptly falls, slides, or is washed away, and (4) in regions of fragile or soluble rock.

Realistic Exercises. — Examine pebbles and boulders and observe the difference between the weathered surface and the surface of a fresh fracture. One may be lighter or darker, rougher or smoother, than the other, according to the kind of rock. The depth to which weathering has penetrated is often plainly visible, and some specimens may be found in a crumbling condition throughout. If a cliff of bed rock is accessible, observe the *talus* or pile of fallen fragments which lies at its foot. Examine the place of contact between the bed rock and the mantle rock above and observe whether the change is gradual or abrupt. If a section of bed rock is freshly exposed, as in a quarry, the depth to which air has penetrated is often shown by the staining of the rock along the cracks.

Valleys and Streams. — It is hardly possible to travel anywhere upon the land surface without coming across a valley. Of all land forms it is the most common, — so common as to attract no attention unless it is unusually deep or otherwise troublesome to cross. Valleys exist in great variety and in all dimensions, from a barely visible furrow to a canyon a mile deep; but almost without excep-

tion they are alike in having a stream at the bottom. This universal association of a stream with a valley does not excite surprise, because we expect water to flow along the lowest level. If valleys exist, it is but natural, as we say, that streams should find and follow them. But let us turn this proposition around and consider its reverse side. If streams exist, is it not natural that their courses should be marked by valleys?

Run-off. — If the course of a stream is followed up, it will be found to be joined at intervals on either side by *tributaries*, each of which flows in a valley usually proportioned to the size of the stream. The main stream and its valley grow smaller above the mouth of each tributary until they are reduced to a tiny rivulet flowing in a furrow, and finally come to an end at a spring, pond, or swamp, or upon the smooth slope of a hillside. If any tributary is followed up, it also is found to divide like the trunk of a tree into smaller branches and rivulets. The surface of the land on either side slopes toward the stream or one of its tributaries, and at the same time there is a continuous slope downstream from the head or tip of every branch. If the slope is ascended from the stream, at a greater or less distance a point is reached where the surface begins to slope away from that stream toward some other stream. A more or less definite line may be found which marks the junction of the two slopes and separates the water flowing into one stream from that flowing into the other. If this *divide* or water parting is followed, it is found to pass around the heads of all the tributaries and to inclose the *basin* or area from which water drains into the stream *system*. Some part of the rain falling upon any basin sinks into the ground, but a large part runs down the slopes. At first this water forms a thin and scarcely

perceptible sheet; but it soon gathers into little rills which join one another and grow larger until they flow into one of the permanent branches of the stream system. The smallest branches flow only while it rains, and their grooves or gullies are dry most of the time. The permanent branches are supplied from ponds, swamps, glaciers, or springs.

Near the sources of the stream the slopes are apt to be steep, the current swift, the channel narrow and deep and perhaps interrupted by rapids and falls. The bed is strewn with boulders, pebbles, or coarse gravel. Farther down, as the slope becomes more gentle, the bed is smoother, rapids are less frequent, and are separated by long reaches of quiet water, and the channel becomes wider, shallower, and more crooked. The loose material is less coarse and consists chiefly of fine gravel and sand. Here the water course is likely to become double and to consist of a wide outer *valley* which the stream covers only at high water and through which the narrower *channel* winds irregularly from side to side. Still farther down, the valley may become very much wider and consist of an extensive *flood plain* bounded by *bluffs*. Here the ordinary channel follows a meandering course, full of zigzag bends and horseshoe curves. The slope is gentle, the current sluggish, and the bed obstructed by sand bars and mud banks. The stream finally empties into a larger stream, or into a lake or the sea.

Fig. 31. – A mountain stream.
(Rainbow Falls, Ute Pass, Colo.)

These are the usual conditions of *run-off* or the escape of rainwater from a *hydrographic basin*.

Fig. 32. — Small stream meandering in a flood plain; sand bar and small terraces.

Transportation. — But this is only half the story. It does not require a very close study of a stream to discover that it is not only a stream of water but also a stream of mantle rock, that the crust of the earth itself is flowing away through the same channel. Some streams are clear and some are muddy, but all carry a portion of mantle rock. The work of the stream is most rapid and most impressive at high water and in the upper parts of its course. Where the current is swift it rolls and pushes pebbles along the bottom, and at times of flood is able to move even large boulders.

Fig. 33. — Boulders in bed of stream.

In the middle course, where the current is moderate, it may be seen to carry sand or to roll it along the bottom, and the inside of every bend is marked by a deposit of sand left as the water went down after the last flood. In the lower course, where the current is very gentle, only clay or the finest sand is carried, all the coarser material having been dropped farther upstream.

Fig. 34. — Sand bar and bluff at bend of river.
(Mississippi R., below St. Cloud, Minn.)

Rock fragments of all sizes are buoyed up by the water so as to lose one third or more of their weight, and are in consequence more easily moved than when out of water. The current of a stream does not flow smoothly onward, but is disturbed by the irregularities of its bed so as to be thrown into ripples and eddies. This irregular motion helps to keep the fragments from settling. In a smooth, gently flowing river the mud may often be seen boiling up from the bottom in hundreds of places where an upward current comes to the surface. Even over a smooth bed the current has a wavy up and down movement which throws the sand at the bottom into cross ridges or ripples, with the longer slope upstream. The finer the particles of rock, the more slowly do they settle in water and the more easily are they kept *in suspension;* therefore, sand is carried along by a slower and smoother stream than gravel, and clay by a slower stream than sand. The size and weight of the particles which a stream can carry in suspension increase rapidly with the velocity of its current. A current of one third of a mile an hour will carry clay; of two thirds of a mile, fine sand; of two miles, pebbles as large as cherries; of four miles, stones as large as an egg.

Material in suspension usually manifests itself by making the water turbid or muddy, but streams also carry invisible rock material *in solution.* The most common materials transported in solution are salt and

lime. It is dissolved lime which makes water hard, and leaves a crust on the bottom of a kettle in which hard water is boiled. The ability of a stream to carry material in solution is not affected by the velocity of the current, for the material is not deposited except by evaporation or some chemical change.

Corrasion. — Wherever a stream runs over bed rock it wears the rock away slowly by solution, but a stream which carries sediment in suspension may wear away such rock rapidly. A clear stream acts upon rock like a piece of paper rubbed upon wood, a muddy stream like a piece of sand paper. If a stream is not overloaded with sediment and can carry sand or coarser particles rapidly, it cuts or files its way down into the crust of the earth through the hardest rocks. The grains of sand and gravel not only wear away the stream bed, but wear upon one another. Boulders and pebbles which are rolled and tumbled about in the current have their corners and edges worn off, and become smaller and more rounded as they travel on. Only the hard ones can endure such harsh treatment without being reduced to powder. This explains why gravel stones are seldom angular or soft.

Corrasion is most rapid where (1) the slope is steep, (2) the volume of water large, (3) the quantity of sediment sufficient, but not too great, and (4) the bed rock soft or friable.

Erosion. — All over the surface of a stream basin the crust of the earth is being crumbled to pieces by the agents of weathering. Gravity and the wash of the rain drag and push the mantle rock thus formed down the slopes into the stream. The current of the stream transports the material to lower levels, and in doing so cuts its own channel deeper. Thus the land is everywhere being torn down and carried away toward the sea. The

lowering of the land surface by weathering, transportation, and corrasion is called *erosion* or *degradation*, and its most efficient agents are gravity and running water. In regions of small rainfall and steep slope, corrasion is more effective than weathering, and erosion goes on much more rapidly near the streams, which cut their channels and valleys deeply into the face of the country. In regions of large rainfall and gentle slope, weathering and rainwash are more efficient than corrasion, and erosion is more uniformly distributed over the basin, though still most rapid near the streams.

Summary. — From these facts it appears not only that a stream of running water is competent to make a valley, but that it must necessarily do so, and that a small stream is able to make a large valley if it is given time enough. The surface of the land is cut by innumerable valleys; running water is the only agent everywhere present which is known to be capable of doing such work: therefore *a stream valley is regarded as the depression or trench which the stream itself has cut.*[1] Its bottom is or has been at some time covered by the stream, and it is bounded by relatively steep banks or bluffs. The channel sometimes occupies the whole width of the valley and sometimes only a small portion of it.

Realistic Exercises. — Let the student visit any convenient stream and see for himself as many of the above described features and processes as can be found. Let him watch the stream in action, during or just after a rain, and see what it does with sediment under varying conditions of fineness and current. At some favorable point supply it with fine and coarse material and observe the result. Shake up clay, sand, and gravel in a tall bottle of water and observe the manner in which they settle. A stream a foot wide is doing the same kind of work in the same way

[1] Care should be taken to distinguish between the *valley* and the *basin*, which is popularly called valley.

as the largest river, and one may be known by studying the other. It is of the greatest importance that stream action be actually studied in the field.

"*Every river appears to consist of a main trunk fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys, communicating with one another, and having such a nice adjustment of their slopes that none of them join the principal valley either on too high or too low a level: a circumstance which would be infinitely improbable if each of these valleys were not the work of the streams which flow through them.*" — JOHN PLAYFAIR, 1802.

CHAPTER V

THE MISSISSIPPI RIVER SYSTEM

THE basin drained by the Mississippi River and its tributaries has an area of about one and a quarter million square miles and is one of the largest in the world. On the west

Fig. 35.

it is separated from the basins of streams flowing into the Pacific by the crest of the Rocky Mountains. On the north the divide between it and the basins of the Nelson and the St. Lawrence is low and flat. On the east it is

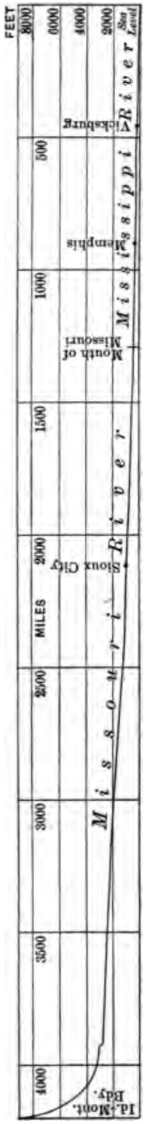


Fig. 36. — Profile of Missouri-Mississippi River.

bounded by the Appalachian highland, and on the south a slight elevation forms a parting between its waters and those of the minor streams flowing into the Gulf of Mexico. The main stream flows from the northwest corner of the basin along a nearly central line more than 4000 miles to the Gulf. It is divisible into three sections, which differ widely in volume of water and other characteristics. (1) The Missouri extends from its source to its junction with the upper Mississippi near St. Louis, more than 2800 miles. (2) The middle Mississippi extends from the mouth of the Missouri to the mouth of the Ohio, 200 miles. (3) The lower Mississippi extends from the mouth of the Ohio at Cairo to the Gulf, 1075 miles. The principal tributaries from the western highland are the Yellowstone, Platte, Arkansas, and Red. The volume of the main stream is almost doubled by the upper Mississippi, which joins it from the north, and it receives a still larger accession of water from the Ohio, which drains a northeastern arm or lobe of the basin. The distance in a straight line between the sources of the Missouri and the Ohio is nearly 1800 miles, and from the extreme northwest corner of the basin to the mouth of the river is about 2000 miles.

The Missouri River. — The Missouri rises at the crest of the Rocky Mountains in southwestern Montana by three forks, the

longest of which, the Jefferson, is fed by the melting snow which fills an old volcanic crater surrounded by peaks 9000 to 11,000 feet in elevation. It flows through deep gorges and glacial lake basins, a mountain torrent descending 4200 feet in 400 miles, to the point of junction with the Madison and Gallatin forks. Thence the Missouri breaks through the Big Belt Mountains by the

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Fig. 37. — Great Falls of the Missouri.

"Gate of the Mountains," a canyon 1200 feet deep, passes a series of rapids and falls, one of which, the Great Falls, has a perpendicular drop of 87 feet, and near Fort Benton, 600 miles from its source, enters the plateau known as the "Great Plains." The Yellowstone escapes from the volcanic region of the National Park over falls 350 feet high and through a canyon 800 feet deep, and joins the

Missouri 400 miles out on the plains.

From its source to the Great Falls the Missouri has an average fall of ten feet per mile; from the Falls to the mouth of the Yellowstone, two feet four inches per mile; from the Yellowstone to the junction with the Mississippi, less than one foot per mile.


Fig. 38. — Gorge of the Yellowstone.

The rainfall of the Missouri basin is less than twenty inches a year, and the source of water supply is largely from the melting snows upon the mountains. The volume of water varies greatly, being at high water in June about thirty times as great as at low water in November. The loss by evaporation is so great that the river in summer actually grows smaller as it advances across the plains, and it succeeds in discharging at its mouth only twelve per cent of the total yearly rainfall in its basin. As a result of this the river is overloaded with sediment, and justifies its name, "Big Muddy."

The Missouri Valley. — Through a great part of its length the valley consists of three trenches, one within another. The widest trench, or valley proper, five or six miles across, consists of a flat or gently sloping plain, covered with the deposits of the river and its tributaries, and bordered by bluffs or terraces. Winding through the valley is a second trench or bed of the river occupied at high water, and on the bottom of this the low water channel swings from side to side.

The Platte, Arkansas, and Red Rivers. — The Platte and the Arkansas stretch from the mountains across the dry plains, and are subject

to conditions similar to those of the Missouri. Both grow smaller by evaporation, and the Platte is at times a mile wide and only six inches deep. The Red is far enough south to catch the rains from the Gulf, and is less variable in volume.

The Upper Mississippi rises among the lakes and forests of northern Minnesota, at an elevation of about 1500 feet above the sea. It flows by a tortuous course from lake to lake, with intervening rapids, about 600 miles to St. Paul; its average fall in this course is about fifteen inches per

Fig. 39. — Flood plain on upper Mississippi River.
(Near St. Cloud, Minn.)

mile. From St. Paul to its junction with the Missouri, 660 miles, its average fall is about five inches per mile. From St. Paul to the sharp bend at Muscatine, the valley is generally two or three miles wide; below Muscatine its width is seldom less than five miles.

The upper Mississippi has a basin whose area is only one third that of the Missouri, but the rainfall is thirty-five inches, which enables it to flow as a strong stream more than half a mile wide at its mouth, and to contribute nearly as much water as does the Missouri. It is subject to less fluctuation in volume than either the Missouri or the Ohio, but has

a period of high water from February to July. It is lowest in December, but is always navigable without difficulty as far as St. Paul. Its banks are marked by many high and picturesque bluffs.

The Middle Mississippi resembles the upper Mississippi in the character of its valley, which is five to seven miles wide, and bordered by limestone bluffs. Its channel is much divided by islands formed by deposits from the muddy water of the Missouri. Its fall is seven and one half inches per mile.

The Ohio.—The basin of the Ohio is less than one half as large as that of the Missouri, but the rainfall is forty-three inches, and the river discharges about three fourths as much water as the Missouri and upper Mississippi combined. It rises by two nearly equal branches, — the Monongahela from West Virginia, and the Allegheny from northwestern Pennsylvania. After a course of about 300 miles each from the summit of the Alleghany Mountains, and a fall of 1000 feet, they unite at Pittsburg, 700 feet above the sea, and nearly 1000 miles from the Mississippi. Between Pittsburg and Cairo the river presents a series of shoals and rapids separated by reaches or pools in which the water is deeper and the fall very slight. At the Louisville rapids there is a fall of 23 feet in 2.25 miles.

The valley of the Ohio is deeply cut into the Alleghany plateau, which slopes westward from the mountains to Indiana. The valley is usually not more than one or two miles wide, and bounded by steep bluffs from 100 to 400 feet high (see Frontispiece). The river is from a half mile to one mile in width, and is bordered by a continuous flood plain. It is subject to excessive fluctuations of volume, and at the highest stage discharges thirty-four times as much water as at the lowest. The spring rains and melting snows of February and March sometimes raise its level at Cincinnati seventy feet above low water mark, and the droughts of summer sometimes reduce its depth to two or three feet. In the last 200 miles of its course the bluffs become lower and the valley wider, with a corresponding expansion of the flood plain to ten or more miles,

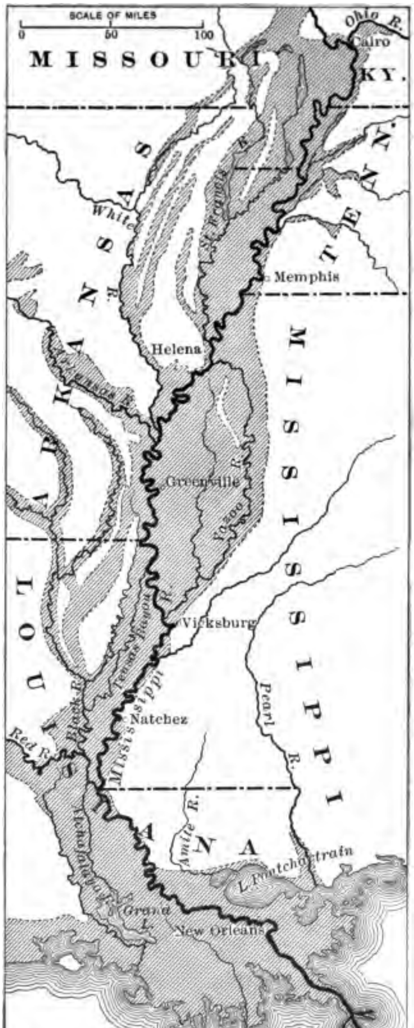


Fig. 40. — Lower Mississippi flood plain.

through which the river winds in a manner similar to that of the lower Mississippi. The Ohio is generally navigable for small boats as far as Pittsburg.

The Lower Mississippi. — The alluvial valley of the lower Mississippi from the mouth of the Ohio to the Gulf is 600 miles long, but the distance as the river flows is nearly twice as great (1075 miles). The width of the flood plain varies from 25 to 80 miles. It is bounded on the east by clay bluffs 100 to 300 feet high. There are also bluffs on the west side as far down as the Red River, but they are not so prominent as those on the east.

The course of the main channel of the Mississippi is near the east bluff as far as Memphis, then it crosses to the west side of the valley at Helena, but soon crosses again to the east bluff, which it strikes at

Vicksburg and follows as far as Baton Rouge. The surface of the valley is mostly below the level of the river banks, and is traversed by an intricate network of side channels and sluggish streams, some of which receive water from the Mississippi as well as discharge into it. The valley contains four large basins. The St. Francis basin lies on the west side of the river, and extends from a point above Cairo nearly to the mouth of the Arkansas. The St. Francis River flows through it parallel with the Mississippi, receives all the small tributaries from the west, and empties into the main stream. The Yazoo basin lies on the east side of the valley and is drained by the Yazoo River, which begins in a branch leading out of the Mississippi above the mouth of the St. Francis, flows near the east bluff, receives all the eastern tributaries, and joins the main stream near Vicksburg. The Tensas basin lies on the west side below the Arkansas, and is drained by the Tensas bayou through the Black River into the Red River. Below the mouth of the Red lies the basin of the Atchafalaya, a river which receives water from both the Red and the Mississippi, and pursues an independent course to the Gulf, which it enters 100 miles west of the mouths of the larger stream. Thus the alluvial valley is traversed throughout its length by a secondary channel on the opposite side from the main stream and parallel with it, which receives water both from the main stream and from the tributaries, to be discharged at some point farther down.

The main channel is extremely tortuous, and frequently divides into two or more channels, which inclose islands or bars. Figure 41 shows its course near Greenville, Miss., where the river appears to be wriggling from side to side in a series of S curves. On the inside of each bend, and on the downstream side of each tongue of land, there is a sand bar, while on the opposite side the water is deep and swift. The swifter current on the outside of each bend, and on the upstream side of each tongue, cuts away the bank at those places, while the slower current on the opposite side, by depositing sediment, builds a new bank. Thus the tendency of such bends is to grow more crooked and to travel downstream. There is a tendency also for the narrow neck of land, which separates one bend from the next,

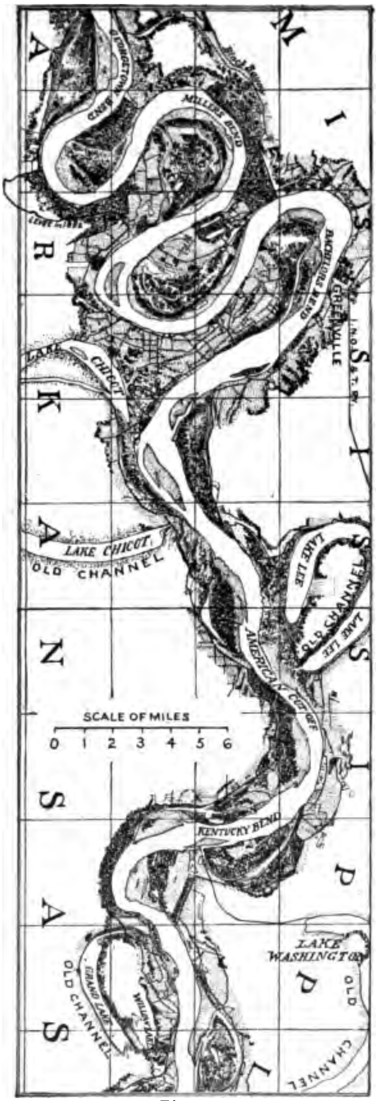


Fig. 41.

to grow narrower. Finally, at some time of high water, the river cuts through or runs over the neck. The slope and fall previously distributed throughout the long bend are now concentrated in the new and short cut, and the current there has such a velocity as to widen and deepen the channel very rapidly, forming a permanent *cut-off*.

Lake Chicot and Lake Lee (Fig. 41) are old bends of the river, which have been cut off and partly filled with sediment. Thus while the river is growing more crooked in one place, it straightens itself in another, and the average sinuosity remains about the same. The valley abounds in horseshoe- or crescent-shaped lakes, all of which were once portions of the channel, and show how the river, in the course of ages, has shifted its bed from one side of the valley to the other, and has occupied at some period every portion of it.

Floods. — As may be inferred from what has been said of the Missouri and Ohio, the lower Mississippi is subject to great floods,

which give it more than ten times the volume it has at low water. The water rises 53 feet at Cairo, 36 at Memphis, 48 at Helena, 53 at Vicksburg, and 15 at New Orleans. If not artificially restrained, the river at high water spreads out and covers nearly the whole valley from bluff to bluff. As the water overflows its banks, the current is checked rather suddenly by its shallowness and by the willows and other vegetation. It consequently drops the larger and coarser part of its load of sediment within a mile or two of the channel, and builds up its banks higher than the general level of the valley floor, forming natural *levees*. The flood water deposits a thin layer of fine mud over the whole submerged country, and returns through the numerous *bayous*, or side channels, to the main stream farther down the valley.

Fig. 42. — Levee, Mississippi River.

Fig. 43. — Crevasse, Mississippi River.

Thus the spaces inclosed by the network of channels become platter-shaped depressions, many of which are occupied by cypress swamps. The natural levees upon both sides of the river have been raised by artificial embankments of earth designed to prevent the high water from flooding the valley; but frequently the river breaks through the levee, forming a *crevasse*, which rapidly widens and transmits a raging and destructive torrent of water. Below the mouth of the Red the rise of

the river is much less because the surplus water escapes through the Atchafalaya, which sometimes carries all the water of the Red and one third that of the Mississippi.

The Delta. — At a point 300 miles above the mouth of the Mississippi, the Atchafalaya, the first *distributary*, or branch which does not rejoin, leaves the river (Fig. 40), and thence carries part of its water to the Gulf. This point is the present head of the Mississippi *delta*, an area of 10,000 square miles of lowland and marsh, much of which is scarcely above the level of the sea. The Mississippi River carries to the Gulf a load of fine mud, sufficient to cover a square mile about 270 feet deep every year. Thus the delta is being gradually extended into the Gulf. About fifteen miles from the sea the river divides into three arms called "passes," which subdivide into smaller arms, each of which has built for itself natural levees which appear above the waters of the Gulf as narrow tongues of land, the whole forming a tract called "the Goosefoot."

The mouth of the South Pass is kept open for large vessels by *jetties* or embankments built upon each side in such a manner as to confine and quicken the current and compel it to deepen the channel across the bar.

Other Features. — The alluvial valley of the lower Mississippi is a very broad and shallow trench cut through loose sedimentary material, chiefly sand and clay. The depth of this material varies from 100 feet at Cairo to more than 1000 feet at New Orleans. The width of the river channel varies from a half mile to two and a half miles; the depth of the river at low water, from five feet to 150 feet. The fall from Cairo to the head of the delta is less than six inches per mile; through the delta at low water it is but a small fraction of an inch per mile. The average volume of water discharged is about 600,000 cubic feet per second, and the velocity of the current varies from one mile to four miles per hour. The lower Mississippi is one of the muddiest rivers in the world, the greater part of its sediment being furnished by the Missouri. The increase of volume and slope at high water quickens the current and enables it to deepen and straighten the channel. At the same time the overflow deposits sediment and builds up the general level of the flood plain.

At low stages of water the current is feeble and easily deflected by any obstruction. Consequently it staggers from side to side under a load which it drops at one place and picks up again at another. Thus it wriggles about all over the surface of the valley and maintains it, on the whole, at about the same width. There is some evidence which indicates that it is slowly raising its bed and banks. The final result of its work is the extension of its delta out into the Gulf and the building up there of a pile of sedimentary strata more than 1000 feet thick.

Work of the Mississippi System. — The vast system of the Mississippi furnishes examples of almost every variety of stream and stream work. The head waters of the Missouri rush over rapids and cataracts, and are able to corrade mountain gorges and canyons. The upper Mississippi is busy in draining and slowly destroying a multitude of glacial lakes. The Ohio has cut a deep trench in the Alleghany plateau, and is now engaged chiefly in widening it. The lower Mississippi has reached its *base-level*, or the lowest level to which its current and load will permit it to reduce its bed, and is now sawing sidewise at places into the restraining bluffs. The whole system is tearing down the land, and carrying it into the Gulf, at a rate which lowers the average level of its basin one foot in about 3500 years.

The lower Mississippi is said to be in its *old age* because its destructive work is nearly accomplished, and it can now do little more than transmit the waste material supplied by its tributaries. The Ohio and its tributaries have hardly yet reached *maturity* because they have the greater part of their possible task of land degradation still before them. The branches of the upper Missouri are *infant* streams, which have just begun the work of tearing down and carrying away the great mass of the Rocky Mountains. If nothing interferes, the condition of old age already approaching in the lower Ohio will creep up that stream and up the Mississippi and the Missouri and their tributaries, until the plateaus and the mountains disappear and the Mississippi basin is reduced to a low and nearly featureless plain.

Summary. — The Mississippi system may be taken as a typical example of most of the great river systems of

the world. Its head waters descend from lofty mountains, and its middle course is through a region of moderate elevation and of large average rainfall. The slope of its bed is steep near its source, and decreases more and more slowly to its mouth; that is, *its longitudinal profile is concave to the sky* (see Fig. 36). The ramification of its main stream into numerous branches, like the limbs, branches, and twigs of a spreading tree, the occurrence of rapids, cataracts, gorges, and lakes among its head waters, and their absence elsewhere, the wide and gently flowing currents of its middle course, and the large proportions of its alluvial valley and delta are common characteristics of great rivers.

Exercise. — Examine physical maps of the different continents and compare the following rivers with the Mississippi, as to area and form of basin, length, fall, tributaries, origin of head waters, course, alluvial valley, and delta: Amazon, Orinoco, Plata, Hoang, Yangtze, Ganges, Amur, Lena, Yenisei, Obi, Volga, Danube, Mackenzie, Yukon, Kongo, Niger.

CHAPTER VI

THE COLORADO RIVER SYSTEM

THE Colorado River system drains a series of lofty plateaus surrounded by still loftier mountains. The greater part of its basin lies between 5000 and 10,000 feet above the sea. Its farthest sources are in the mountains of western Wyoming, at an elevation of 12,000 feet, whence the Green River flows southward about 400 miles. In southeastern Utah the Green is joined by the Grand, which rises among the highest peaks of the Park Range in Colorado. The junction of these rivers forms the Colorado, which flows southwestward 200 miles, then turns to the west for 150 miles, then flows south about 300 miles to the Gulf of California. The whole length of the Green-Colorado, by the windings of the river, is not far short of 2000 miles. Its principal tributaries, — the Grand, San Juan, Little Colorado, and Gila, — are all upon its eastern side, its basin is widest near the

Fig. 44. — Basin of the Colorado River.

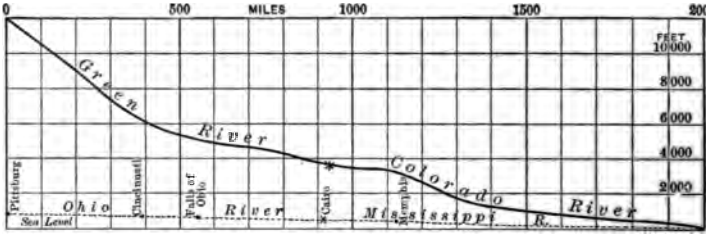


Fig. 45. – Profiles of the Green-Colorado and Ohio-Mississippi rivers.

mouth of the river, and in contrast with the wide-spreading, symmetrical, elmlike branchings of the Mississippi, the map of the Colorado system resembles a bent and broken trunk with a few straggling and one-sided limbs. Over

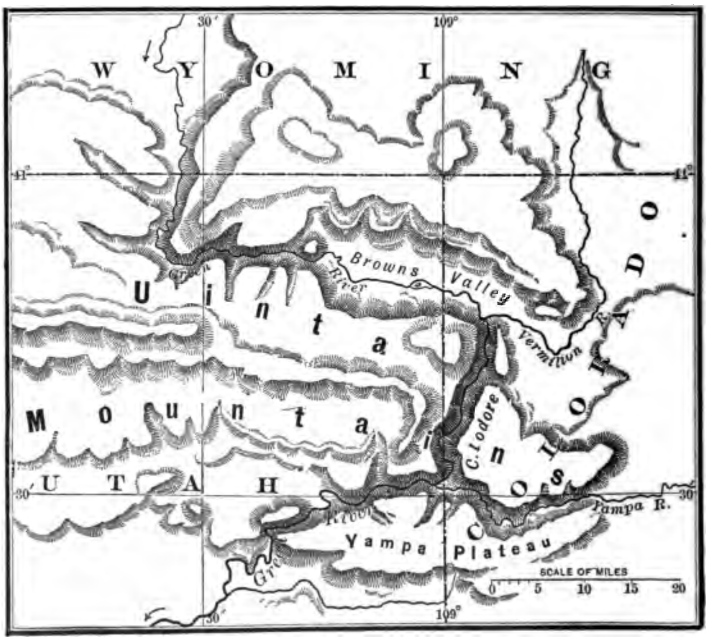


Fig. 46. — Part of Green River.

Fig. 47.—Canyon of Lodore, by which Green River leaves Browns Valley.

most of the basin the rainfall is less than ten inches per year, and the principal sources of water supply are the rains and melting snows upon the mountains which stand along

its border, the Rocky Mountains on the east and north, and the Wasatch on the west. In northern Utah the Uinta Mountains project eastward from the Wasatch halfway across the basin.

The Upper Green River. — North of the Uinta Mountains the Green River traverses a plateau into which it has cut a broad valley about 1000 feet deep. On reaching the northern foot of the mountains the river enters a canyon which penetrates directly into the range to a point within five miles of the crest, then turns abruptly to the east and runs along the axis, gradually crossing toward the south. The easterly course of the river for forty miles is through a broad valley (Browns Valley) which continues to the end of the range. The river, however, does not follow this valley around the end of the mountain ridge, as it apparently might, but turns sharply to the southwest and crosses the range through the Canyon of Lodore (Fig. 47). On the south side of the mountains it cuts off the end of a projecting plateau at a point where a course a few miles longer would have carried it around that elevation.

Fig. 48. — The Terrace Canyons.

The Terrace Canyons. — Between the valley of White River (Fig. 53) and the mouth of the Grand, a distance of about 150 miles, the surface of the country is like a staircase which has been tipped backward so that each tread or step slopes up toward the riser next below (see Figs. 48 and 53). A person traveling southward parallel with Green River ascends a moderate slope for 60 miles and reaches an elevation of 3000 feet above the river. At this point the upward slope ends in a line of very steep cliffs, which drop down in a few miles nearly to the river level. The next sloping step is 25 miles wide and the cliffs

at its edge are 2000 feet high. The third step is 50 miles wide, and its border cliffs are 1200 feet high.

Green River cuts across the terraces from north to south directly against the slope of the steps, and in doing so forms three canyons, each of which is shallow at the upper end and gradually increases in depth to the lower end.

Cataract Canyon. — South of these terraces the river makes a slight easterly turn and by doing so runs into an elevated ridge, but before reaching its central axis turns again westerly and runs out of the ridge. In the canyon thus formed (Cataract Canyon) the walls increase in height to about 2700 feet near the middle, then decrease to the lower end. In the midst of it the Green and Grand rivers unite to form the Colorado at a depth of 1200 feet below the general level of the country.

Fig. 49. — Marble Canyon.

Glen and Marble Canyons. — From the mouth of Dirty Devil River to the mouth of the Paria the Colorado flows through Glen Canyon, which has nearly perpendicular walls from 200 to 1600 feet high, carved into a great variety of glens, alcoves, and amphitheaters.

Below Glen Canyon is Marble Canyon, which increases in depth from 200 feet at its head to its foot, where the walls are 3500 feet high. Its width is about twice its depth, and it has been cut through a bed of marble 1000 feet in thickness, which stands in smooth, precipitous cliffs on either side.

Grand Canyon. — At the foot of Marble Canyon, the Little Colorado comes in from the east, the main stream changes its general direction from southwest to west, and

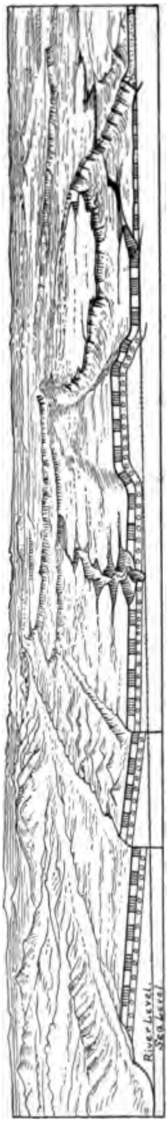


Fig. 50. — Section of Colorado plateaus near Grand Canyon.

the Grand Canyon begins. This so far surpasses all other canyons in magnitude as to render them comparatively insignificant. The river passes through a series of plateaus, the surface of which lies from 6000 to 8000 feet above the sea, by a channel which varies from three-quarters of a mile to more than one mile in depth. The slope of the river is steep and broken by many rapids. The surface of the plateau is highest near the upper end of the canyon, where it stands 6000 feet above the river; but owing to the rapid descent of the river bed, the canyon is seldom less than one mile deep all the way to its mouth at the Grand Wash, where the plateau terminates in a line of cliffs facing westward. The plateaus are about 130 miles in width, but the course of the river is so crooked that the Grand Canyon is 218 miles long. In its upper or eastern portion the walls are very irregular and cut by side canyons into recesses, alcoves, and amphitheaters. It is here a valley from eight to twelve miles wide, out of which rise a multitude of ridges, spurs, gables, towers, and pinnacles, mountainous in size and endless in variety of detail, forms which have been carved out of the massive strata of the plateau. Through the midst of them, but sunk far below, winds the slender thread of the river from one fourth to one

half mile wide. In the lower or western half, the walls are more regular and the canyon is distinctly double, consisting of an upper and outer canyon five or six miles wide, and 2000 feet deep, through which winds an inner gorge one or two miles wide and 3000 feet deep.

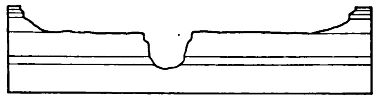


Fig. 51. — Section of double canyon.

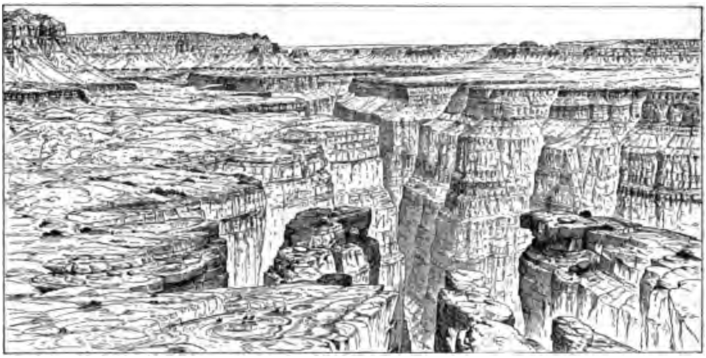


Fig. 52. — Grand Canyon at foot of Toroweap, showing double canyon.

Lower Colorado. — A few miles below the mouth of the Grand Canyon, the Colorado turns abruptly to the south and flows 300 miles (by the meanders of the river 600 miles) through a nearly rainless country to the Gulf of California. As it approaches the gulf, its flood plain is ten or more miles in width, and it resembles the lower Mississippi.

The Gulf of California once extended more than 100 miles farther to the northwest than it now does. The mouth of the Colorado River was then on the eastern side of the gulf, but the river extended its delta until it formed a barrier which cut off the head of the gulf from the main body. The water evaporated from the basin thus formed, and now known as the Salton Desert. This is 266 feet below sea level, and is sometimes temporarily flooded by the waters of the Colorado.

Summary. — The characteristics of the Colorado River distinguish it above all other rivers in the world. From the north side of the Uinta Mountains to the foot of the

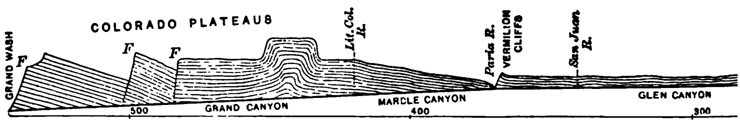
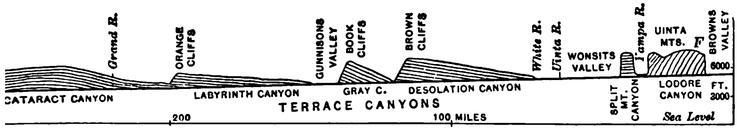


Fig. 53. — Section along the canyons of the C

Grand Canyon, a distance as the river flows of nearly 1000 miles, the stream follows a course entirely regardless and apparently in defiance of the surface and slope of the country. Mountain ranges and massive plateaus stand across its path, but they seldom turn it aside. In several instances it seems to go out of its way to cut through them or to run into a ridge and out again. Not only in particular cases, as through the Terrace Canyons, but in the greater part of its course, it flows directly opposite to the general slope of the country. The elevation of the Colorado plateaus above the sea is several thousand feet higher than that of Browns Valley. As a result of this, the river flows for a thousand miles, with trifling exceptions, at the bottom of a steep-walled trench, sunk thousands of feet below the general level of the country.

Origin of Canyons. — The first impression made upon one who sees these canyons, or pictures of them, is likely to be that some force acting from the interior of the earth has broken the crust apart and made a great crack, which the river had only to follow. But this theory will not bear investigation. Cracks in the earth-crust do occur, but none have ever been found so crooked as this series of canyons. Cracks are almost always accompanied by *faulting*, or a displacement of the rock on one side up or down; but in the canyons the strata on one side correspond to those on the other, as if they had once extended across the chasm. Several faults occur in the Colorado plateau region (see *F*, Fig. 53), but they are not parallel with



orado River, shortened by omitting bends.

the river, which runs across as regardless of them as it is of mountains. Each tributary river has a canyon of its own, and so, too, has each smaller branch. Each canyon is adjusted to the size of the stream which flows through it, and the level of its bottom is usually adjusted to that of the larger canyon into which it empties. Thus, the whole tract of plateaus and mountains is divided by a labyrinth of ramifying canyons into irregular blocks. Every rod of this network, from source to mouth and from top to bottom, shows evidence of being the work of running water. The conclusion is unavoidable, that *the streams have carved their own canyons.*

A stream can not begin to cut a valley until it has begun to flow along the course of the valley. It begins at the top and works downward. It is evident that the Green-Colorado River never could have flowed over mountains, up slopes, and across plateaus on such a surface as now exists along its course. The only solution of the problem is found in the supposition that the river established its channel when the surface sloped continuously, or nearly so, in the direction of its flow, and that it has maintained nearly the same general course and level through all the subsequent movements of the earth-crust in its basin. It has acted very much like the saw in a sawmill, which cuts a groove into anything presented to it. The earth-crust has been pushed up, arched, and broken, and the blocks have been tilted at various angles, while the river system has been sawing its canyons.

The river has been able to corrade thus deeply because (1) its slope is steep, through the canyons six to twenty feet to the mile, and its current swift, (2) it is supplied with a full stream of water from the mountains, and (3) it carries a sufficient load of sediment for active corrasion without being overloaded and choked. The canyons are narrow, because at elevations below 8000 feet the region is nearly rainless, weathering goes on very slowly, and the tributaries which would cut down the walls and widen the valley are few, short, and inconstant. The double gorge of the Grand Canyon furnishes striking proof of the fact that since the river began to flow the country has stood at a much lower level than now. When the wide outer gorge (see Fig. 51) was completed, its bottom was not far above sea level, the river had a feeble current and wound from side to side, eating back the cliffs until its valley became in some places fifteen miles wide. Then came a slow upheaval of the land which gave the river a rapid descent, quickened its activity, and caused it to cut into the floor of the old valley a narrower and deeper canyon.

Work of the Colorado System. — The Colorado River furnishes on the largest scale and in the greatest variety examples of the work of a river which drains an elevated and arid region. Empowered by its rapid descent, it has engraved upon the face of the earth, in plain characters, the story of what running water, together with running sediment, may accomplish. Its short, steep tributaries, flat divides, and narrow canyons are evidences of scant rainfall and relatively small water supply. If the rainfall in the Colorado basin had been forty inches instead of less than ten inches per year, weathering would have been rapid and the river would have been much larger, with longer and more numerous tributaries. In the time which it has taken to carve its narrow canyons, it would have worn down the mountains and plateaus, and perhaps filled the Gulf of California with their débris, as the Mississippi has filled much of the Gulf of Mexico.

The Colorado has been called a "precocious infant" because although it may be called young it has accomplished a great work. Yet it has

done very little in comparison with what remains for it to do. There are other rivers which present characteristics similar to those of the Colorado, but on a smaller scale. The Rio Grande drains an area of arid plateaus lying southeast of the Colorado basin. In passing through the ranges of mountains between Presidio and the mouth of the Pecos it traverses a series of narrow canyons 1000 to 5000 feet deep and 350 miles long. The Snake River, rising from the same mountains as the Missouri and the Green, flows westward through the lava beds of the Columbia plateau by a series of canyons, one of which is fifteen miles wide and 4000 feet deep. The rivers which drain the lofty plateaus of central Asia to the east and south — the Hoang, Yangtze, Mekong, and Brahmaputra — descend to the lowlands through stupendous gorges, some of which have never been fully explored.

Exercise. — Write a comparison of the Mississippi and the Colorado in regard to basin, tributaries, divides, fall, current, rapids, cataracts, valley, and amount of sediment carried.

CHAPTER VII

THE ST. LAWRENCE RIVER SYSTEM

THE St. Lawrence basin may be regarded as a shallow depression in the long eastward slope of North America and as a broad gap in the eastern highlands, connecting the

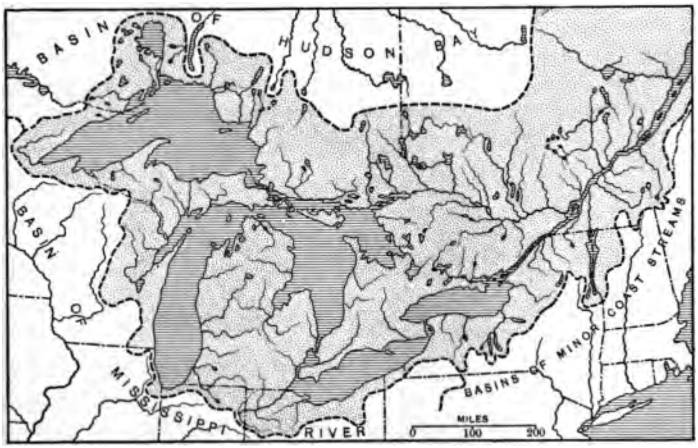


Fig. 54.—Basin of the St. Lawrence River.

central plains with the Atlantic coast. Few places in the divide which surrounds it are more than 1500 feet above the sea, and on the south the divide is in many places less than half as high. About one sixth of the basin is covered by the five Great Lakes which lie close to its southwestern border. The tributary streams, except the Ottawa and Saguenay from the north, are short. The level of Lake Superior is 602 feet above the sea, and the descent from it, through the St. Marys River, to the level of the twin

lakes, Michigan and Huron (581 feet above sea level), is twenty-one feet. Lake Huron is connected by St. Clair River and Lake and Detroit River with Lake Erie, which lies eight feet lower (573 feet). From Lake Erie to Lake Ontario, through the Niagara River, there is

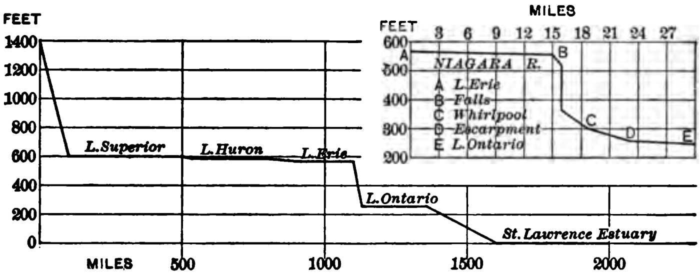


Fig. 55.—Profiles of the St. Lawrence and Niagara rivers.

a drop of 326 feet in thirty miles. The St. Lawrence River leaves Lake Ontario at an elevation of 247 feet, and with an average fall of one foot per mile reaches sea level at Three Rivers, 500 miles from its mouth. Between Lake Ontario and the mouth of the Ottawa at Montreal, the river is wide, straight, swift, clear, bank-full, without floods or flood plain, and with numerous rocky islands and rapids. Some of these peculiarities may be accounted for by the influence of the lakes. Sediment carried by streams into lakes settles there, and the water flows out clear. In the absence of sediment, the river lacks the tools necessary for corrasion, and makes very little impression upon the bed over which it flows: hence the stream channel is but slightly depressed below the top of its banks. Any temporary excess of water supply is spread out on the broad surface of the lakes, and has no appreciable effect in raising their level; consequently floods can not occur in the river below. From Montreal to the mouth the current is

affected by the ocean tides. Below Three Rivers the river is 1000 feet or more in depth, widening into a great estuary, the Gulf of St. Lawrence. A channel about 2000 feet deep extends along the bottom of the gulf, and 300 miles out to sea.

Fig. 56 — Laurentian channel.

The course of the St. Lawrence, including the Great Lakes, presents striking peculiarities. In its upper part it resembles a stream which has been obstructed by a series of dams, above each of which the water is held back in a great pond or reservoir. In its lower part it is not now a river, but an arm of the sea which extends up the valley 500 miles. When the river made this valley and the channel upon the bottom of the gulf, it must have had in this part of its course a current of considerable velocity and it must have carried sediment. These conditions point back to a time when the St. Lawrence system did not contain many lakes and when its basin stood at an elevation of 2000 feet or

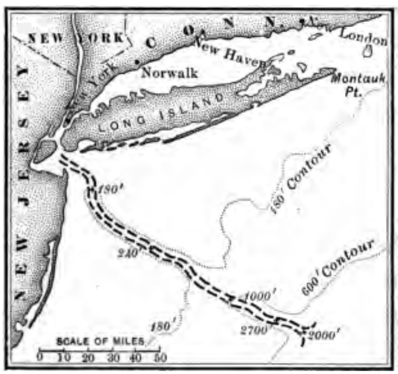


Fig. 57. — Hudson channel.

more above its present level. Since that time the course of the old Laurentian river has been obstructed by a number of dams above which the waters of the Great Lakes are held up to their present levels, and the land has subsided so as to let the sea into the lower valley, converting it into the present broad gulf.

Drowned Valleys.—The lower portions of stream valleys which have sunk below sea level are called *drowned valleys*. The lower St. Lawrence is perhaps the greatest example of a drowned valley in the world, but many other rivers are in the same condition. The old channel of the Hudson River may be traced upon the sea bottom about 125 miles beyond its present mouth (Fig. 57), and its valley is drowned as far up as Troy, 150 miles. The sea extends up the Delaware River to Trenton, and Chesapeake Bay with its many arms is the drowned valleys of the Susquehanna and its former tributaries (Fig. 58). Many of the most famous harbors in the world, as San Francisco Bay, Puget Sound, the estuaries of the Thames and the Mersey, and the Scottish firths, are drowned valleys.

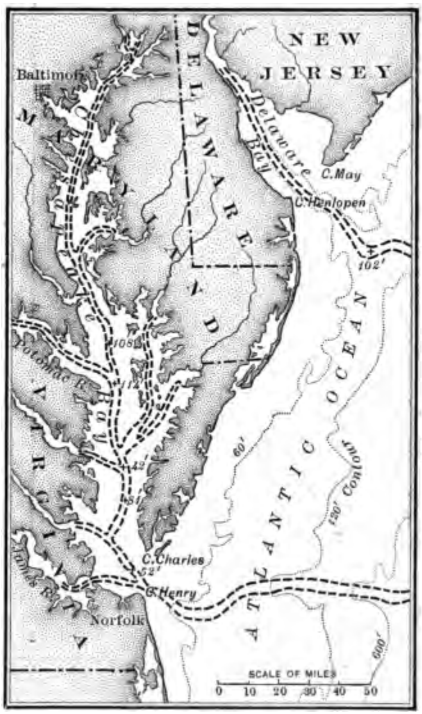


Fig. 58. – Delaware and Susquehanna channels.

The Niagara River and Falls. — The strip of country between Lake Erie and Lake Ontario, twenty-five miles wide,

consists of two plains lying at different levels. The upper plain extends from Lake Erie northward eighteen miles to the edge of an *escarpment* or cliff, where the surface drops steeply down 200 feet to the level of the lower plain, which borders Lake Ontario. Both plains are underlain by strata of sandstone, limestone, and shale, which are not quite horizontal, but slope southward about thirty-five feet to the mile. The arrangement is such that the strata outcrop on the surface in the following order from the shore of Lake Erie: (1) hard limestone (Corniferous), (2) soft shales (Salina), (3) hard, thick-bedded limestone (Niagara), extending to the edge of the escarpment, (4) soft shales and thin-bedded limestones (Clinton) forming the lower part of the cliff and the surface of the lower plain (Figs. 59, 60). The Niagara River flows across these two plains from one lake to the other. Its course is quite direct, so that it makes the whole descent

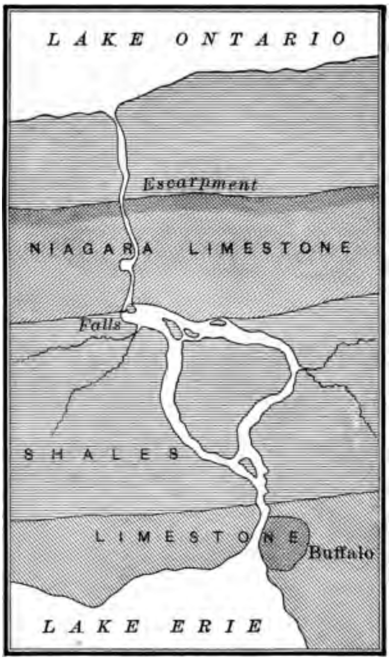


Fig. 59. – Niagara plains.

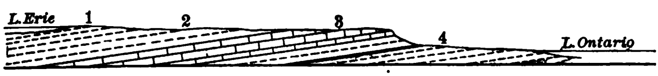


Fig. 60. — Section of Niagara plains.

of 326 feet in about thirty miles. In the first thirteen miles the river is five to twenty feet deep and about one mile wide except where it is divided by Grand Island. The banks are low, and the current moderate. The stream resembles the St. Lawrence below Lake Ontario, and has corraded its channel to a very slight depth. Where it reaches the Niagara limestone, rapids begin, and after rushing down a slope of fifty-three feet in half a mile, the river drops perpendicularly 160 feet into a narrow gorge, which extends seven miles to the escarpment, and there opens out upon the lower plain. The width of the gorge varies from 600 to 1200 feet, and its nearly perpendicular walls rise 200 feet above the water. The slope is very steep and the water rushes through the narrow chan-

Fig. 61.—Cross sections of the Niagara.

nel in a succession of boiling rapids (Fig. 62). Midway in the length of the gorge is the Whirlpool, where an expansion and a bend cause the current to circle around in a complete loop. After passing under itself, it escapes at right angles to the course of the incoming stream. The peculiar features of the river which demand explanation are the falls, the gorge, and the sudden change in the character of the valley from wide and shallow to narrow and deep.

In the walls of the gorge, strata of varying composition and hardness are exposed. At the top the Niagara limestone forms a bold, perpendicular face about fifty feet high. Below, a series of soft Clinton shales are weathered into a steep slope. About midway of the height harder strata of Clinton limestone form a low cliff, below which soft shales and sandstones again form a steep slope to the water's edge. The strata on one side of the gorge correspond exactly in character and position with those on the other side, so that there is no suggestion of a fault or displacement. At the falls the same strata occur in the same order.

Fig. 62. – Niagara Gorge.

Fig. 63. — Niagara Falls.

The upper (southern) part of the river joins the gorge at a right angle (Fig. 59), so that the portion of the stream which forms the American Fall drops over the side of the gorge, while the larger Canadian or Horseshoe Fall plunges in at the end, the two streams being separated by Goat Island (Fig. 63). At the brink of both falls the Niagara limestone overhangs like the cornice of a house, so that a considerable space intervenes between the falling water and the face of the precipice (Fig. 64). This space behind the American Fall is called the "Cave of the Winds," and is large enough to admit visitors. At the foot of the American Fall lie many great blocks of limestone which have fallen from above (Fig. 65). From the brink of the Horseshoe Fall similar blocks many yards in area have been observed to fall from time to time. A comparison of the positions of the brink of the Horseshoe Fall as determined by surveys made in 1842 and in 1890 (Fig. 66) shows that the fall has moved upstream on an average five feet a year.

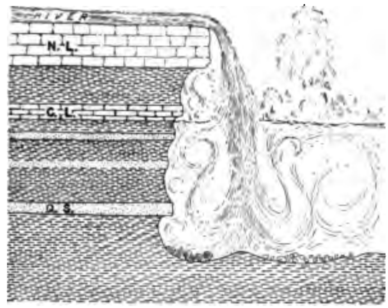


Fig. 64. — Section of Niagara Falls.

Fig. 65. — The American Fall.

Method of Recession. — The water passing over the brink of the falls strikes the bottom with great force, and boils upward again, while a portion of it constantly splashes back against

the face of the precipice behind. In winter blocks of ice are hurled back against the wall, and add to the destructive effect of the splashing water. The soft shales are worn away, leaving the limestone above unsupported, which sooner or later falls by its own weight. In the Horseshoe Fall the force of the water is sufficient to toss the fallen blocks about, and to use them as tools to undermine the limestone still farther. The American Fall is too feeble to break up and carry away the blocks. Consequently they have accumulated and now protect the precipice somewhat from further attack. From all these facts it seems evident that at some time in the past the Niagara River began to fall over the escarpment (Fig. 59), and that, by the processes just described, the falls have traveled upstream to their present position. The Niagara gorge, therefore, has not been made by downward corrasion, for which the stream, on account of the absence of sediment, is poorly fitted; but it is the result of excavation and undermining by the falls. This work has been made possible by the position of the hard Niagara limestone on top, and the softer strata beneath, and by the fact that the water carries little sediment. If the rock in the bed of the river above the falls were softer, or if the river carried sediment, it would corrade downward and reduce the height of the fall by beveling off its edge. When the falls have receded to a point where the soft Salina shales are on top, and the Niagara limestone at the bottom, they will change from a

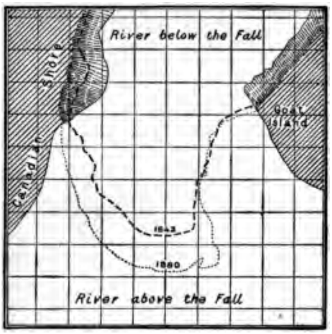


Fig. 66. — Map of Horseshoe Fall.

perpendicular cataract to a succession of rapids. A harder layer on top and a softer layer beneath are necessary conditions for the maintenance of a perpendicular fall. Such conditions occur frequently, and on almost any stream may be found falls which reproduce on a small scale the overhanging ledge, the deep pool, and the gorge which exist at Niagara in such magnificent proportions.

The St. Lawrence basin has had a long and eventful history. The river was once mature and had a bed which sloped continuously in a curve concave to the sky, like the Ohio and Mississippi. By processes which will be described in Chapters X and XI, it has been *rejuvenated*, or compelled to begin again the work of eroding its basin and grading its channel. It is now an example of a ponded stream, which, by reason of the lakes in its course, is almost deprived of sediment and hence of the ordinary means of stream corrasion. It is cutting down its bed very slowly, except in the Niagara section, where peculiar conditions may enable it, in time, to extend its gorge back to Lake Erie. That lake will then be drained and its bed will be traversed by a river which, by deepening its channel, will drain in turn the three upper lakes.

Exercise. — Using any available source of information, learn the characteristics of the Nile River and compare it with the type rivers described in Chaps. V, VI, and VII. In what respects does it resemble the Mississippi? the Colorado? the St. Lawrence? In the same way study the Rhine, the Zambezi, the Indus, and the Euphrates.

CHAPTER VIII

UNDERGROUND WATERS

Ground-water. — Some portion of the rain which falls upon the surface of the land sinks into the ground. The quantity varies with the steepness of the slope, the covering of vegetation, and the porosity of the rock. Fine clay and compact limestone absorb water, but permit very little to pass through. Sand and coarse sandstone absorb rather less water than clay, but transmit it quite freely. Any rock which is traversed by joints and cracks, as is usually the case in nature, allows the rainfall to penetrate the crust of the earth. Some regions of limestones and lavas are so broken up by fissures that there are no surface streams, the entire drainage being through underground channels. Ground-water is continually rising by capillary attraction through the soil and keeps growing plants alive in dry weather. It is also the source of supply for wells and springs. If a well is bored to a depth below the level at which the ground is saturated with water it fills up to that level. If the water level outcrops on the surface, a spring occurs at that point.

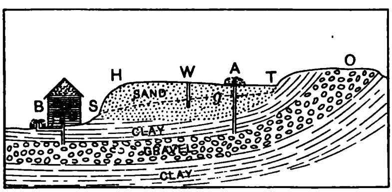


Fig 67.

In Fig. 67 the rain falling on the surface *HT* penetrates through the sand until it reaches the surface of the clay beneath, and moves slowly toward its lowest point *S*. But it stands higher in the sand than the level of the top of the clay, because a certain pressure is necessary to overcome friction and force the water through

the sand. The lowest level of ground-water is at a height where the resistance due to friction just counterbalances the pressure due to the accumulated water. Since the friction increases with the distance which the water has to flow through the sand to its point of escape, it will hold the water up to a higher level below *T* than below *H*. There will be a spring at *S*, and a well sunk at *W* down to *g* will strike water. Both spring and well will be unfailing if the rainfall is sufficient to supply the outflow from them. If a permeable stratum, as gravel, lies below an impermeable stratum, as clay, and receives rain upon its outcropping surface, as at *O*, it may become filled with water up to the level of *O*. Then if a well starting at a lower level, as at *A* or *B*, is sunk until it taps the water-bearing gravel, the water will rise above the mouth of the opening, and a flowing or *artesian* well will be obtained. In a boring at *B* the pressure may be sufficient to raise the water to the top of a house or to make a fountain.

The ground-water everywhere tends to flow or creep slowly toward the valleys, where it accumulates or feeds the surface streams. In regions of small rainfall and deep, permeable soil the greater part of the drainage may take place through the mantle rock instead of on its surface. By digging in the bottom of a dry stream bed, a good supply of water may often be found, and a dam sunk to the proper depth may force the hidden stream to rise to the surface. Streams sometimes increase in volume more rapidly than can be accounted for by their visible tributaries. In such cases they receive additions from the percolating ground-water.

Fig. 68. — Stream flowing from a cave.
(Donaldson's Cave, Lawrence County, Ind.)

Underground Streams. — In some limestone regions the drainage is wholly subterranean and the earth-crust is

honeycombed with tortuous passages and tunnels which frequently widen into large and lofty chambers or caves. The surface of such a region is pitted with funnel-shaped

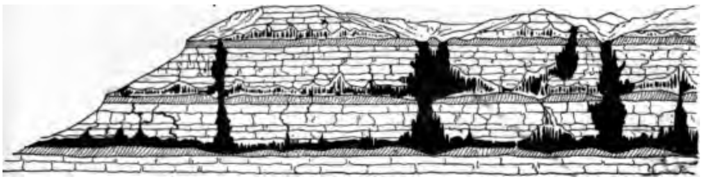


Fig. 69. — Section of caves.

depressions or *sinkholes* which have no outlet except at the bottom. In some cases a stream enters an opening in the side of a cliff or hill, and after flowing some distance underground reappears upon the surface. Many surface streams in limestone regions flow from caves (Fig. 68).

Fig. 70. — Natural Bridge, Virginia.

Caverns. — The rain-water percolates through the soil, enters the small crevices and joints of the limestone, and by reason of the carbon dioxide which it contains, is able to dissolve the rock and gradually to enlarge the passage. It often follows some plane of stratification, hollowing out large, irregular rooms along that level, and, finding its way to a lower level, repeats the process there. The result is a cave in two or more stories, connected by numerous passages.

In places the intervening floor breaks down and a lofty hall is opened from top to bottom. The place where the roof of a cave has fallen in is marked upon the surface by a sinkhole or inclosed valley without visible outlet. Where the roof of a large tunnel has fallen in, a portion may remain standing and form a *natural bridge* which spans the now open valley. The Natural Bridge, in Virginia, was formed in this manner.

Where water carrying lime in solution drips from the roof of a cave, it may evaporate, or lose some of its carbon dioxide, or both, and thus becoming incapable of holding the lime, deposit it in a long, pendant *stalactite*, like an icicle. At the point where the dripping water strikes the floor, more lime is deposited and a slender, columnar *stalagmite* is built up to meet the stalactite. Thus columns, statues, "curtains," "altars," "organs," and other strange and beautiful forms are added to the characteristic scenery of caves. Mammoth Cave in Kentucky, Wyandotte and Marengo caves in Indiana, and the Luray Cavern in Virginia, are among the most famous and extensive in the world. Wyandotte Cave has a measured length of more than four miles, and contains one room 210 feet long, 90 feet wide, and 65 feet high.

Fig. 71. – Stalactites and stalagmites. (Marengo Cave, Ind.)

Mineral Springs. — Water which percolates a considerable distance through the earth-crust meets with a variety of minerals which it dissolves and transports to the surface, where it emerges as a mineral spring. The nature and quantity of the mineral matter held in solution vary with the character of the rocks traversed and the temperature of the water.

Many springs of moderate depth and temperature form deposits of lime, iron, or other minerals about their mouths, but springs of hot water in volcanic regions bring to the surface vast quantities of silica which contribute to the formation of extensive masses of rock. Hot springs sometimes take the form of *geysers*, from which, at regular intervals, the water spouts to a great height. Old Faithful, in the Yellowstone Park, throws a stream of hot water 150 feet high about once

Fig. 72. — Hot spring terraces, Yellowstone Park.

an hour (Fig. 73). These periodic outbursts are due to the gradual accumulation and final explosion of steam at great depths.

The Work of Ground-water contributes to the same end as that of surface water. It dissolves and eats away the substance of the earth-crust and transports it, in some cases to higher levels, but finally, by one route or another, to the sea. Its channels take the form of covered tunnels or caves, but these are often changed into valleys by the caving in of the roof. It extends the processes of

weathering and erosion to indefinite depths, prepares the rock for more rapid attack by surface agents, and plays an important part in the tearing down and removal of the land.

Fig 73. — Old Faithful.

Realistic Exercises. — Men engaged in sinking wells can furnish much information concerning the ground-water of any locality. The student should investigate the depth of wells in his neighborhood, the materials through which they pass, and in which water is found; the source, quantity, and permanence of the supply; the quality and temperature of the water; the levels at which springs occur; the deposits, if any, at their mouths; and the nature and extent of caves, if any exist. Mines, quarries, and other excavations often show the penetration of ground-water and the streams which traverse the joints and fissures of the rock.

CHAPTER IX

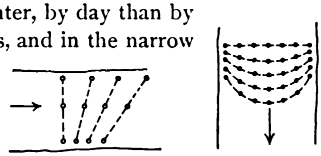
GLACIERS

Upon the tops of mountains and in the polar regions upon lower land, most of the moisture which falls from the clouds is in the form of snow. If the quantity which falls is greater than the quantity which melts and evaporates, the difference remains from year to year, and the ground is always covered with a mantle of snow. The line above which snow is always present is called the *snow line*. Its height above the sea is greatest near the equator and in regions of dry climate, and least near the poles and in regions of moist climate, varying from 18,000 feet to near sea level. On mountain tops snow is blown off the peaks and slides down the slopes until it accumulates in the valleys to the depth of hundreds of feet. In the summer part of the snow is melted by day and frozen again at night, rain occasionally falls upon it, and it changes from dry, loose snow to a coherent mass, half snow and half ice, called *névé*. The pressure of the upper layers upon those below consolidates them and finally changes the névé into clear, solid ice. It is the same process of thawing, wetting, freezing, and pressure by which

Fig. 74. — Snow-capped mountains.
(Mont Blanc, Switzerland.)

boys make hard, icy snowballs. When the pile of ice, névé, and snow becomes deep enough, it begins to spread out at the bottom under the pressure of its own weight. A basin filled with such material overflows by a stream of ice, somewhat as a basin filled with water overflows by a river. Ice thus formed from snow instead of water is called *glacial* ice; and any large mass of it is called a *glacier.*

Alpine Glaciers. — Glaciers were first studied in the Alps, and those mountains still offer to the tourist and student one of the richest and most accessible fields for glacial observation. The snow line on the Alps lies at a height of about 8500 feet, and the longest glaciers descend in the course of ten or fifteen miles to the 4000-foot level. They are essentially rivers of ice, each of which conforms to the windings and irregularities of its own valley. The rate of motion is seldom more than two feet a day, or more than 250 to 500 feet a year, and therefore quite imperceptible to ordinary observation. If, however, a row of stakes is set across the ice in a straight line with stakes on the banks, the line will gradually become more and more convex downstream and the rate of movement of each stake may be measured. By this method it has been discovered that the motion is more rapid in the middle than at the sides, in summer than in winter, by day than by night, on steep than on gentle slopes, and in the narrow than in the wider parts of the valley. The ice does not fill every nook and recess of the valley or set back into side ravines as water would. If stakes are driven into the side of the glacier in a vertical row, after some weeks the line will be found to incline downstream (Fig. 75), showing that the upper layers move faster than the lower.

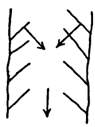


Movement at side of a glacier. Movement on surface of a glacier.

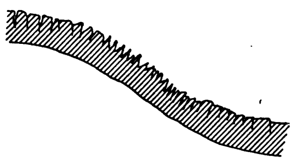
Fig. 75.

Realistic Exercise. — In a long box or trough place a mass of some plastic substance like pitch, tar, shoemaker's wax, or asphalt. Stick a row of upright pins in a straight line across it and set the box in an inclined position. If the material is kept moderately warm, it will flow slowly downward, and after a few days the row of pins will be found to be convex and inclined downstream. Why?

Crevasses. — The surface of a glacier is traversed in various directions by cracks called *crevasses.* One set extends from each side toward the center diagonally upstream. These are due to the unequal rates of motion. The ice in the center moves faster, while that at the sides drags against the valley walls, and the ice is pulled in two, or breaks at right angles to the direction of the strain (Fig. 76). In passing around a bend the ice upon the outer side is put upon the stretch, and crevasses appear which often close up again after the bend is passed. At points where the valley bottom is convex or the angle of slope increases abruptly, the ice becomes deeply crevassed (Fig. 76). Such places correspond to ripples in a river, which remain stationary while the water moves on.



Diagonal crevasses.



Longitudinal section of an ice fall.

Cross section of a glacier.

Fig. 76.

Wherever the ice is suddenly subjected to a pulling or stretching strain, it breaks readily like a brittle body, and in many cases it becomes so broken by a maze of cracks that it resembles a heap of sharp, angular blocks. Where the stream moves on more smoothly, many of the crevasses close up again, and their sides unite so completely that all trace of the break disappears. If a crevasse remains open long, the warm air gains access to its surfaces, which melt unevenly, and when the sides come together again, they do not fit and the break remains unhealed. Ice which has been extensively crevassed never fully recovers its former solidity and smoothness.

Causes of Glacial Motion. — To discover how a rigid, brittle body like ice can be squeezed out from under the weight of its own mass and can then move down a wind-

Fig. 77. — Davidson Glacier, Alaska.

ing valley in conformity with its varying direction, width, and slope is a problem of great difficulty.

Plasticity. — While ice is very brittle under sudden strain, it is slightly *plastic*, and will stretch or bend or flow like very stiff molasses candy without breaking, if it is only given sufficient time.

Breaking, Pressure Melting, and Regelation. — The readiness with which ice breaks under small strains and its cracks are again healed has been already described. When water freezes, it expands, as broken pitchers and burst pipes testify every winter. Conversely, when ice is compressed it melts. If two blocks of ice with dry surfaces are pressed together, slight melting occurs; when the pressure ceases, the water thus formed freezes and the blocks are cemented together. (Try the experiment.) This process is called *regelation* (freezing again). The consolidation of snow into ice and the movements of the ice may be accounted for by the fact that breaking, pressure melting, and regelation are constantly going on.

Realistic Exercises. — Suspend a lump of ice weighing about twenty pounds in a loop of wire. The wire will slowly cut into the ice and pass completely through it, but the cut will heal as fast as made, and only a layer of air bubbles will remain to show where it was. The ice is melted above the wire by pressure and freezes again below it.

Fill a strong iron box or cylinder with damp snow or small pieces of ice and subject them to great pressure under a screw or lever press; they will be consolidated into one mass having the form of the box.

Melting and Expansion by Freezing.— A glacier moves more rapidly in summer than in winter, by day than by night, and in the warmer region near its lower end than in the colder region near its source. The fact that wherever and whenever there is the most water in the ice, it moves fastest, indicates that its motion is due partly to melting. Also whenever the water formed by melting freezes again, it expands and tends to push the whole mass down the slope.

Fig. 78. — Aletsch Glacier, Switzerland.

The causes and methods of glacial motion seem to be complex. The principal forces at work are gravity, heat, and expansion by regelation. It is impossible to determine just how much each contributes to the result. The whole truth can not be expressed by such a simple statement as that a glacier slides or flows or creeps down its valley. It probably moves by sliding, flowing, and creeping.

Ablation. — Throughout the length of a glacier the ice is disappearing more or less rapidly by evaporation and melting, but, of course, most rapidly in the warmer region toward its lower end. On a clear summer day the surface of the ice is traversed by streams of water which unite into drainage systems similar to those upon the land. After a longer or shorter course they usually drop into some crevasse and disappear in the depths below. Around these cascades the ice melts more rapidly, and a cylindrical well (*moulin*) is formed, extending downward out of sight. The melting and evaporation are sometimes sufficiently rapid to lower the general surface of the ice as much as a foot in one day. The glacier finally reaches a point in its course where the *ablation* or destruction of ice equals the supply brought down, and the glacier comes to an end.

At this point a stream of yellowish or milky water issues from the mouth of a cave or tunnel in the ice and carries away the whole drainage of the valley above. It is as if a long block of ice were pushed toward a hot stove at such a rate that it melts as fast as it comes. The ice as a whole is moving forward, but the end remains at nearly the same point. The end of a glacier is not strictly stationary, but retreats or advances with changes of season and climate.

Transportation. — An Alpine glacier carries upon its surface and in its substance a large quantity of rock débris which it has gathered from the sides and bottom of its valley. On the steep slopes of the mountains weathering goes on rapidly, and great *avalanches*, or slides of snow, rock, and earth, descend upon the surface of the ice stream. This rock and earth are piled near the margin in a long ridge called a *marginal moraine*. When a tributary joins the main glacier the united marginal moraines continue down the central part of the combined glacier as a *medial moraine*. These piles of rock and dirt protect the ice beneath them from melting, so that by the ablation of the

bare ice they may come to lie upon a ridge a hundred or more feet high. The morainic material rolls down the sides of this ridge and spreads out over a wider band, so

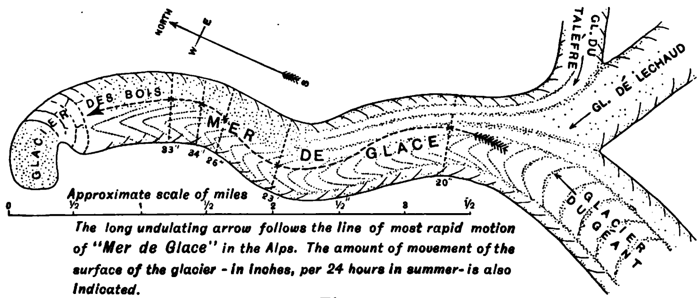


Fig. 79.

that at the lower end of the glacier the whole surface of the ice is often buried under a mass of gravel and boulders.

A large amount of rock débris, known as *ground moraine*, accumulates at the bottom of the glacier and is pushed and dragged along with it. It is largely composed of clay, sand,

Fig. 80. — Terminal moraine.
(Middle Blase Dale Glacier, Disco I., Greenland.)

and gravel. The whole mass of rock and earth carried by a glacier upon its surface, in its substance, and at its bottom is called *glacial drift*, and by the final destruction of the ice

it is dumped at the lower end in a confused heap known as a *terminal moraine*.

Abrasion. — Pure ice moving over a rock surface would probably do little more than sweep away loose material; but a mass of ice a thousand feet thick, having sand, gravel, and boulders frozen into its bottom, acts like a flexible rasp which fits the irregularities of its bed and *abrades* or wears it away in a peculiar and striking manner. All sharp angles and corners are rubbed off. The softer portions of the bed rock are scooped out into hollows and the harder portions are left projecting; but all the slopes and outlines are smoothed and rounded.

If the bed rock is hard and fine-grained, it may be polished as finely as any marble or granite monument. More than this, the glacier leaves its signature upon the rock in the form of parallel *striæ*, or scratches, from the finest hair lines to grooves a foot or two deep (Fig. 96). Pebbles and grains of sand, grinding along over the rock floor under the weight of the ice above, wear away the surface and leave scratches all running in the same direction. A rock surface which has been thus planed, polished, and striated is said to be *glaciated*. The pebbles and boulders themselves are subjected to the same process, and every terminal moraine contains thousands of them which present one or more glaciated faces. The general effect of a glacier upon its valley is to deepen it, to change its cross section from a V-shape to a U-shape, and to leave it with a gently undulating surface more or less covered with glacial drift.

Fig. 81. — Glaciated boulder.

Glacial Drift is distinguished from all other deposits by well-marked characteristics. (1) Where it has not been redistributed by the water flowing from the melting ice, it is *unassorted and unstratified*. All kinds and sizes of

sediment are mixed up together higgledy-piggledy. (2) The ground moraine is largely a tough clay as full of gravel stones as a pudding is of plums, and containing

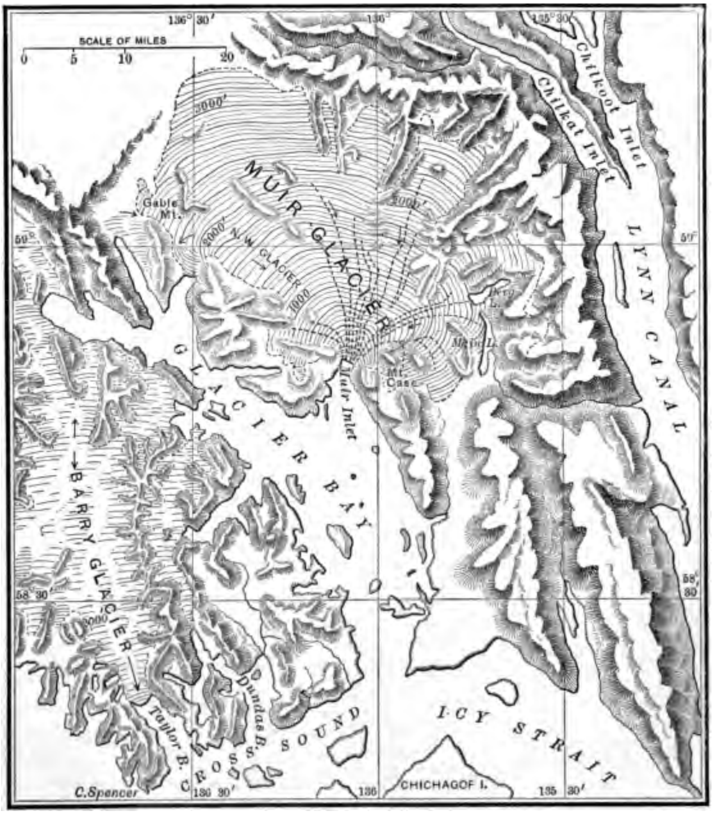


Fig. 82. — Map of Muir Glacier.

glaciated boulders of all sizes. It is called *till* or *boulder clay.* (3) The terminal moraine is likely to contain more sand and gravel than clay, and any number of large boulders of every variety of rock existing along the course

of the glacier which brought them. The stones are generally angular or subangular, and may be glaciated on one or more sides, but are not smoothly rounded, like water-worn pebbles. (4) Glacial drift is largely composed of *foreign material*, that is, of rock fragments which have come from a distance and are unlike the bed rock upon which they lie.

Exercise. — Write a comparison of an Alpine glacier and a river in regard to origin, course, movement, transportation, corrasion, deposits, and work accomplished.

"The track of a glacier is as unmistakable as the track of a man or a bear." If a glacier should entirely disappear by ablation, what evidences of its former existence would remain?

Fig. 83. — **Muir Glacier, showing ice wall.**

Alaskan Glaciers. — Some of the glaciers which descend the mountainous coast of Alaska are different in form from any known elsewhere. The Muir Glacier (see Figs. 82 and 83) is fed by twenty or more ice streams, which descend

into and fill an amphitheater thirty to forty miles in diameter. The medial moraines, marking the lines of flow, converge toward a single outlet about a mile wide, through which the surplus left from ablation, the drainage of 800 square miles of snow field, escapes into an arm of the sea. The ice stream ends in a jagged wall not far from 1000

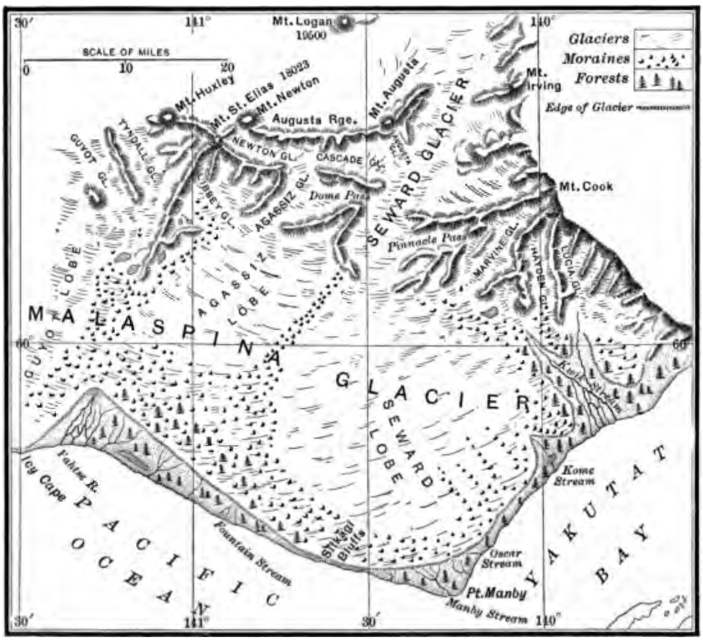


Fig. 84. —Map of Malaspina Glacier.

feet high and standing 200 feet above the water. Large masses break off from this cliff and fall into the water with a loud roar. Other large masses are loosened from the foot of the cliff beneath the water and rise to the surface with violent splashing. Thus a continuous procession of icebergs float away and melt in the sea.

The Malaspina Glacier, at the foot of the Mt. St. Elias range, is in form the reverse of the Muir (see Figs. 84 and 82). Many separate streams from the mountain valleys unite into a plateau or lake of ice which spreads out to a width of fifty miles. The ice front extends along or near the shore of the ocean for a distance of seventy miles. The surface of the glacier is undulating, like the western prairies, and in the central portion is mostly free from moraines and dirt, but broken by thousands of crevasses. The outer edge of this ice sheet seems to have been for a long time stagnant and has become covered by a thick coating of sand and gravel derived from the moraines. Upon this soil a dense growth of trees and shrubs has sprung up, forming a forest under which the ice is, in places, 1000 feet thick.

Fig. 85. — Map of the Greenland ice cap.

The Greenland Ice Cap. — Greenland is a plateau about 1500 miles long and 800 miles wide in its widest part. Two thirds of its surface is buried beneath a sheet of perpetual snow and ice. The general elevation of the ice plateau is 7000 to 8000 feet in the central area, gradually

decreasing to 2000 or 3000 feet toward the coast, giving to the island a surface form like that of a loaf of bread, gently rounded in the middle and steeply sloping at the edges. Beyond 50 or 75 miles from the coast no mountain peak, rocky islet, or other sign of land rises above the sea of névé. The white, featureless expanse is unbroken by crevasses or water courses and unstained by dirt or dust. The whole mass seems to be moving outward in all directions, and, as it approaches the coast, becomes broken by projecting peaks of rock and extensively crevassed. Its edge is divided into numerous long tongues which escape down the narrow valleys to the sea. The largest of these yet described forms the Humboldt Glacier, which advances into the sea with a wall 60 miles long and 200 to 300 feet above the water. From the various projecting tongues of ice innumerable bergs break away and crowd the adjacent waters. The rate of motion in the Greenland glaciers sometimes reaches 50 or 100 feet per day.

Fig. 86. — Iceberg.

The Antarctic Ice Cap. — The region around the south pole as far as latitude 70° seems to be covered with an ice cap similar to that of Greenland, but of vastly greater extent. Explorers sailing in that direction are stopped by an unbroken wall of ice, 200 to 300 feet high, from which flat-topped bergs (Fig. 87), often half a mile in breadth, *break off and* float away. The area included within this

ice wall is about 4,000,000 square miles, or larger than the whole of Europe. The névé fields, if not continuous over the whole region, must be very extensive and moving out-

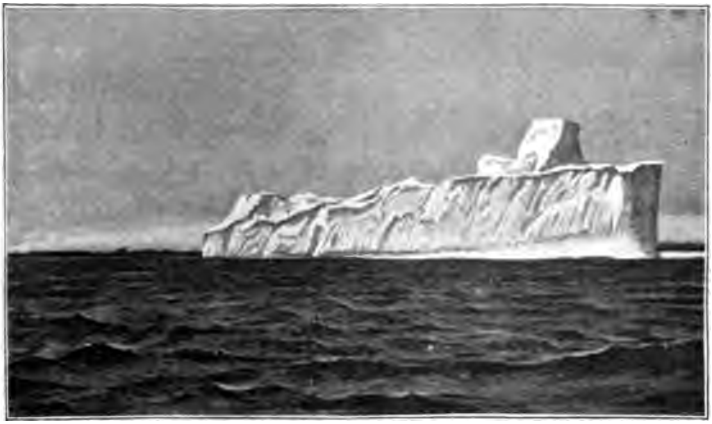


Fig. 87. — Antarctic iceberg.

ward in all directions to supply the quantity of ice which is discharged.

Continental Glaciers. — Glaciers which are not confined to valleys but spread over wide tracts of country, like the ice caps of Greenland and the Antarctic region, are called *continental*, and are the only surviving representatives of vast ice sheets which once covered a large part of North America and Europe.

CHAPTER X

THE DRIFT SHEET OF NORTH AMERICA

Fig. 88. – Boulders from a terminal moraine.
(St. Joseph County, Ind.)

THE greater part of the northern half of North America is covered with a sheet of mantle rock similar in essential character to the ground moraine now forming under the glaciers of the Alps, Alaska, and Greenland. In the United States this sheet of mantle rock extends as far south as the Ohio and Missouri rivers. Its thickness varies from a few feet to several hundred feet, its average depth being not less than 100 feet. The greater part of its mass consists of a stony clay containing pebbles of all sizes, many of which are glaciated. There are also extensive deposits of sand and gravel, often well assorted, but also mixed with each other and with clay in all proportions. More conspicuous than these, but constituting only a small

percentage of the whole, are thousands of boulders of all sizes up to that of a small house. The pebbles and boulders represent a great variety of material. An hour's search is often sufficient to collect fifty or one hundred species of rock *nearly all foreign to the region where they lie*, and the majority of them foreign to the United States.

Fig. 89. A boulder.
(Near Camden, Maine.)

Most of these "erratics" or "lost rocks" are recognizable as fragments of the igneous and metamorphic rocks of the old Laurentian highland of Canada, and in some instances they can be traced back to a definite locality from which they must have come originally. Large masses of metallic copper from the shores of Lake Superior have been found buried in the soil of Indiana, and some of them are glaciated. Boulders of a peculiar conglomerate, consisting of pebbles of red jasper disseminated through a ground mass of white quartz, are scattered over Ohio, Indiana, and Illinois, and on account of their striking colors attract popular attention. They must all have come from one parent ledge of similar rock on the north shore of Lake Huron.

The surface of this sheet of mantle rock is traversed by a complex system of ridges which have the form and composition peculiar to terminal moraines. In hundreds of places where the bed rock has been exposed by natural or

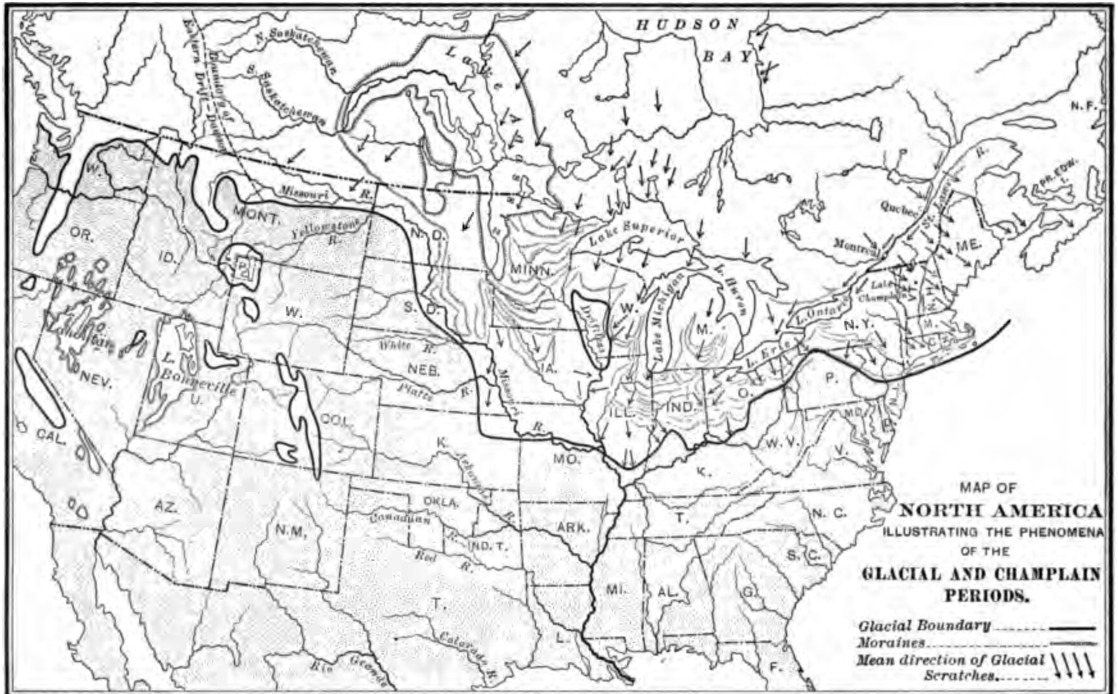
artificial means it is found to be glaciated, the grooves and scratches having a general north-south direction.

These features admit of but one explanation. This sheet is a vast deposit of glacial drift. The evidence has now accumulated in such mass, variety, and accordance as to make it impossible to doubt that at a comparatively recent period the northern part of North America was covered with an ice sheet like that of Greenland, extending as far south as the glacial boundary shown on p. 125.

If the lines of glacial scratches are traced back northward, they point to the region around Hudson Bay as the location of the central snow field. From this region the ice moved southeastward over New England, southward over the Middle states, southwestward over the Western states, westward nearly to the Rocky Mountains, and northward toward Alaska and the Arctic Ocean. The farthest point from the center reached by the ice was in Kansas, a distance of 1500 miles. The area covered was about four million square miles, but it is not probable that it was all covered at any one time.

The Older Drift. — Close examination reveals the fact that the drift is not simple and uniform over the whole area, but is made up of several distinct sheets which overlap one another, like the shingles on a roof. The lowest and outermost sheets together form what is known as the *older drift*, which lies on the surface in parts of Ohio, Indiana, Illinois, Iowa, Missouri, Kansas, and Nebraska.

The margin of the older drift is not usually marked by a ridge or terminal moraine, but thins out to a vanishing edge along the glacial boundary from central Ohio westward. The older drift is extended and partly covered by deposits of fine silt (*loess*), probably the alluvial sediment left by glacial floods. It is also characterized by the occurrence within its mass of buried timber and vegetable débris, so common that the well diggers call such an accumulation "Noah's brush-heap" or "Noah's barnyard." It is probable that the ice sheets which deposited the older drift advanced to their southernmost limit and at once retreated, pausing at but few places in the United States long enough to form a well-marked terminal moraine.



MAP OF
NORTH AMERICA
ILLUSTRATING THE PHENOMENA
OF THE
GLACIAL AND CHAMPLAIN PERIODS.

The Newer Drift. — Partly overlapping the older drift lies a much thicker and more complex sheet of more recent drift, the southern margin of which is marked by a series of terminal moraines, almost continuous from Cape Cod to Alberta.

As will be seen from the map, p. 125, the terminal moraine in the east coincides with the glacial boundary, but in central Ohio the two part company. In the Mississippi valley they are 500 miles apart, but run close together again through the Dakotas. In the interval between them in Wisconsin there is a large area entirely free from drift. The drift sheet is quite thin in New England, but increases in mass westward until in Ohio and Indiana it attains a depth of from 100 to 500 feet.

The Moraines. — The principal irregularities of the surface of the newer drift are due to the long lines of terminal moraines which traverse it. The margin of the ice sheet which deposited the newer drift not only occupied the line of its farthest advance long enough to deposit a massive moraine, but during its retreat it halted at frequent intervals or temporarily readvanced. The line held at each period of halting is marked by a moraine roughly parallel with the previous one. The method of retreat was a step backward and then a long pause, as an army retreating from an enemy's country marches by day and at night halts and throws up intrenchments.

Between the Ohio River and Lake Superior the lines of moraines indicate sixteen successive halting places. A very noticeable feature is the looped or festooned form of the moraine groups, indicating that the ice sheet was divided into several lobes or tongues which advanced independently of one another. This lobation was due to the broad, open valleys of the region. In the valleys the ice was thicker than on the bordering highlands, and consequently advanced farther and melted back more slowly. The basins of the Laurentian lakes seem to have exerted a controlling influence upon the lobing of the ice margin. There was an Erie lobe in Ohio and Indiana, a Saginaw lobe from Lake Huron in Michigan and Indiana, a Lake Michigan lobe in Michigan, Indiana, and Illinois, a Green Bay lobe in Wisconsin, and

Fig. 90. — Map of Erie moraines.

a Superior lobe in Minnesota. In each lobe the ice spread out from the center toward the margin, and in the reëntrant angles between the lobes piled up *interlobate* moraines of huge proportions.

The Surface of the Moraines. — At the edge of the ice the newer drift material was dumped pell-mell in long heaps, while a portion of the ground moraine was pushed forward and a portion gathered under the edge where the ice current was too feeble to carry it farther. In many places the morainic material was deposited in shallow lakes which stood along the ice front, or was carried by outflowing streams far down their valleys. The moraines formed under these conditions have a varied aspect. The simplest are long ridges or swells, rising above the level surface of the drift plain like dead ocean waves. The most massive consist of a belt of hills from two to twenty miles wide, where the drift is piled in a confused assemblage of

domes, knobs, peaks, and irregular ridges, with corresponding hollows between, all in the utmost disorder.

Fig. 91.—A hilly moraine.
(St. Joseph County, Ind.)

The predominating materials are gravel and sand. The feebler moraines present the same features on a smaller scale, forming the "mound and sag" type of surface; or the sags may be absent and the moraine consist of a belt of

Fig. 92.—A kettle hole.
(Near Morristown, N.J.)

low, broad mounds rising from a plain. A moraine line *is sometimes* marked only by a broad belt or strip of sur-

face thickly strewn with large boulders. The relief of a morainic surface forms a unique type of topography, which once seen and understood can be readily recognized.

Kettle Holes form one of the most characteristic features of terminal moraines. They are bowl-shaped or funnel-shaped basins of all sizes

Fig. 93.—A kame.
(Tippecanoe County, Ind.)

and depths, having no outlet, and often occupied by small lakes. Each marks the place where a large block of ice detached from the main mass and partly buried in drift has melted and left a depression, as ice melting under sawdust often does.

Kames are heaps of sand and gravel which have been deposited along or near the edge of the ice by outflowing streams of water. They take the form of mounds and winding ridges with a hummocky and rapidly undulating outline. The material is more or less perfectly stratified. They occur in connection with moraines and are often difficult to distinguish from them.

Fig. 94.—An esker.
(In Auburndale, near Boston, Mass.)

Eskers, or "serpent kames," are long, winding ridges of gravel which extend often for many miles across hills and valleys in the direction of ice movement. They are accumulations formed in the tunnels of subglacial streams or in ice-walled canyons open to the sky.

Drumlins are peculiar rounded and elongated lenticular hills of boulder clay, which were formed under the ice some distance back from the

Fig. 95. — A drumlin.
(Near Amherst, Mass.)

margin, and perhaps correspond to the sand bars in a river. They do not usually occur singly, but in groups which occupy the whole face of the country.

General Results of the Ice Invasion. — The foreign boulders and glacial scratches upon the White, Green, and Adirondack mountains indicate that the ice overrode their summits and was not less than a mile thick over northern New England. Its thickness over the Laurentian highlands may have been two miles.

Fig. 96. — Glaciated rock.
(Summit of Mt. Monadnock, N.H.)

On account of the absence of land projecting above it. the surface of the ice sheet was clean, and lateral and medial moraines were wanting. The drift was gathered up from the bottom, and, except a portion which in some manner became incorporated in

the body of the glacier, was dragged along as a ground moraine. The ice sheet may be pictured as combining the features of the Greenland ice cap with those of the Malaspina Glacier. The great central expanse was smooth and clean, but for many miles back from its margin it was probably covered with gravel and boulders laid bare by the ablation of the upper layers. It may even have resembled the Malaspina in supporting a growing forest.

The action of the ice sheet was vigorous and prolonged and its effects correspondingly great. The present surface features of the region which it covered are largely the result of its work. The regions of ice accumulation in Canada and New England were regions of greatest

Fig. 97. — Drift plain.
(Tippecanoe County, Ind.)

abrasion. Not only were they swept nearly bare of mantle rock, but hills and mountains were worn down, and the surface of the bed rock was pitted with thousands of shallow depressions now occupied by lakes. The rock débris thus formed was carried southward and spread over southern Canada and northern United States. In the region of glacial deposition, previously existing hills and ridges were rubbed down, valleys were filled up, and the surface of the country plastered over with a coat of drift, as a mason plasters a rough stone wall with mortar.

Except in the mountain regions the old surface features were obliterated and a new and much smoother surface was created. The contrast between the broken surface of the country south of the glacial boundary (Fig. 98) and the monotonous smoothness of the drift plain north of it (Fig. 97) is very striking, and in some places the change from one to the other is abrupt.

Fig. 98. — Unglaciated region.
(Near New Albany, Ind.)

The Drift Plain is relieved only by shallow valleys which the streams have cut a little way into it and by the belts of morainic hills which rise here and there from fifty to three hundred feet above its surface. The moraine belts are studded with thousands of ponds and small lakes, and the plain itself abounds in swamps and marshes. On account of the gentle slopes and the short time during which the streams have been at work, the whole region is poorly drained. The drift, however, is the "grist of the glacial mill," and consists of an intimate mixture of rock flour and fragments ground from a great variety of minerals. It contains all the elements of plant food and forms one of the most productive and enduring soils in the world. The drift regions are preëminent in their agricultural resources.

The Preglacial Drainage of the glaciated region underwent profound *modification.* The St. Lawrence River system was completely changed

in character, a subject which will be more fully discussed in the next chapter. The old outlet of the Allegheny and Monongahela rivers, which formed a single northward-flowing stream, was dammed with drift, and their waters were permanently diverted to the Ohio. The northern outlet of the Winnipeg basin in Canada was dammed and the basin occupied by a fresh-water sea (see Lake Agassiz on map, p. 125), which emptied through the Minnesota River into the Mississippi. The course of the Missouri through the Dakotas was displaced one hundred miles to the westward. From the Maine coast the ice extended far out to sea, the lower portions of the stream valleys in Maine were deepened, and by subsequent drowning they have been converted into *fiords*, which give the coast its present extremely ragged outline.

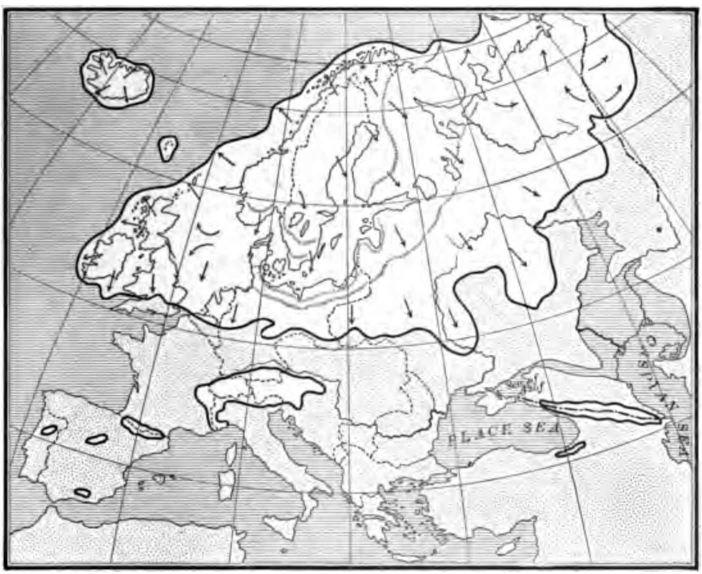


Fig. 99. — Glaciated regions of Europe.

Other Glaciated Regions. — During the glacial period northern Europe passed through a series of ice invasions similar to those of North America, and it now presents similar characteristic features. The general movement of

the ice, the glacial boundary, and the principal terminal moraine are shown upon the map, Fig. 99. The Scandinavian mountains formed the chief gathering grounds, with secondary centers of dispersal in the Scotch highlands and the Alps. The Baltic and North seas were filled with solid ice, as Hudson Bay was.

The glacial period closed at least 10,000 years ago, yet it was so recent as compared with other great changes, and its effects in Europe and North America were so profound and far reaching, that it may well be regarded as one of the most important events in the recent physical history of the world.

Realistic Exercises. — Any student who lives north of the glacial boundary should make himself acquainted with the glacial features in his vicinity. Boulder clay may be readily found and distinguished from other clay; foreign pebbles and boulders may be picked up by the thousand. Glaciated pebbles and glacial scratches on the bed rock are likely to be found anywhere. Deposits of loess, the thickness of the drift, the occurrence of buried timber, drift-filled valleys, changes in stream courses, moraines, kettle holes, lakes, kames, eskers, and drumlins should be looked for and investigated. No region offers better facilities or more interesting subjects for elementary field work than the areas covered by glacial drift.

CHAPTER XI.

LAKES AND LAKE BASINS

In an ideal drainage basin the slope is continuous from the divide to the mouth of the stream. But in nature slopes are interrupted by depressions which are completely surrounded by a rim of higher land and act as reservoirs which detain and store up a portion of the rainfall. Such a depression, if the rainfall is sufficient, fills with water up to the level of the lowest point in the rim and becomes the bed of a lake or pond. Lakes may be regarded as expansions of the streams with which they are connected. They vary in form and size from quiet pools or reaches, where the current of a stream is imperceptible, to veritable inland seas, like the Great Lakes.

Fig. 100.

Diastrophic Basins

The Great Basin.—The largest basins are due to the warping or irregular elevation and depression of the earth-crust by internal forces. The Great Basin of west-

ern United States, lying between the Sierra Nevada and Wasatch Mountains, has an area of about 210,000 square miles. Its surface is divided by parallel mountain ranges into numerous valleys and subordinate basins. The rainfall is scanty and almost confined to the mountain tops.

Great Salt Lake in Utah is the shrunken remnant of a body of water (Lake Bonneville) which was nearly ten times as large as the present lake, stood about 1000 feet higher, and had an outlet by way of the Snake River to the Columbia. During the period of overflow its waters were fresh, but a decrease in rainfall caused its surface to fall below the level of the outlet, and it has become increasingly salt. At various levels around its inclosing rim, its former shore lines, with their wave-cut cliffs, bars, spits, terraces, and deltas, record the work of the waves and inflowing streams of the ancient lake (see Fig. 232).

Lakes of Nevada. — At the time of the greatest extension of Lake Bonneville a large body of water (Lake Lahontan) occupied a very irregular area of 1500 square miles in the western side of the Great Basin, receiving drainage from the Sierra Nevada. This lake, at its highest stage, had a depth of nearly 900 feet, but never had an outlet. Pyramid, Winnemucca, Walker, Humboldt, and Carson lakes now occupy the lower portions of the old lake bed. They are subject to great variation in volume from year to year. At many points in the Great Basin, wet weather lakes gather in times of rainfall and soon dry away, leaving *playas*, or beds of mud, which bake to a hard and cracked crust.

Asiatic Basins. — The great plateaus of Asia include extensive basins and inland drainage systems similar to those of the Great Basin of the United States. The country lying between the Kuenlun and Altai Mountains is of this character. The desert of Gobi is the bed of a dried-up sea, containing in its lowest parts salt lakes and marshes which *rise and fall* with the uncertain water supply. Snow-fed

streams creeping out from the mountain valleys sometimes reach these lakes, but their waters are generally lost or evaporated. Southwestern Asia, including large portions of Persia and Arabia, contains basins either entirely dry or holding in their lowest parts shrunken salt or bitter lakes.

The Caspian Basin. — To the north and west of the plateau country of Asia, and including a large area of southeastern Europe, lies a great low plain which has no outlet to the sea. It contains the Caspian Sea, which has an area of 170,000 square miles and a maximum depth of 3000 feet. The surface of the Caspian Sea is about 90 feet below the level of the sea. The Caspian seems to have been originally part of a gulf which extended southward from the Arctic Ocean, from which it was cut off by the rising of the intervening land. The Aral Sea and Lake Balkash are salt lakes of the same origin as the Caspian.

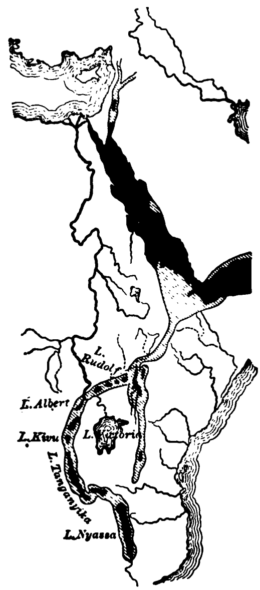


Fig. 101. – Map of east African lake chains.

Rift Basins. — In east Africa there are two extensive chains of lakes and dry basins which are long and narrow and lie, like fiords, between precipitous cliffs thousands of feet in height. One chain extends from Lake Nyassa on the south, through Tanganyika and Albert, to Rudolf, where it is joined by another chain from the south. Thence the line continues northward as a long strip of low land, dotted with lakes and old lake basins, some of which are below sea level, to the southern end of the Red Sea. At the north end of the Red Sea a similar line of depressions extends from the Gulf of Akabah to the Dead Sea and the valley of the Jordan River in Palestine. This deep, narrow valley, nearly 4000 miles long, containing the Red Sea and

more than thirty lakes, has been produced by a series of parallel faults, or cracks in the earth-crust. The block between the faults has subsided, forming the "Great Rift Valley," bounded by high, precipitous walls on either side. The bottom is quite irregular and has been obstructed by many outflows of lava. Lake Nyassa is 350 miles long, 50 miles wide, and 300 to 600 feet deep, and empties southward by the Shire and Zambezi rivers to the Indian Ocean. The largest lake, Tanganyika, is 400 miles long, 20 to 40 miles wide, and 500 to 2000 feet deep, and overflows westward into the Kongo River and Atlantic Ocean. Lake Albert is one of the sources of the Nile. Most of the lakes have no outlet. The Dead Sea is remarkable for the extreme saltness of its waters and for the fact that its surface lies nearly 1300 feet below the level of the sea.

In the northwestern part of the Great Basin there are numerous rift valleys, some of which are occupied by small lakes. Of these, Alvord and Warner valleys in Oregon, Surprise Valley in California, and Long Valley in Nevada are the most notable. Long and Warner valleys

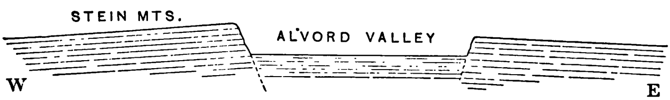


Fig. 102. — Section of Alvord Valley, Oregon.

are continuous, and form a narrow basin 100 miles in length, walled in by sheer precipices in some places 2000 feet high. The Stein Mountains rise 4000 to 5000 feet above Alvord Lake. (See Figs. 150 and 151.) A series of rift valleys extends from central New Mexico, through western Texas, into Mexico.

Glaciated Basins

Lakes are more numerous in glaciated regions than in any other parts of the world. (See maps of northern Europe and North America.) Basins in glaciated regions are of two classes: (1) *bed-rock basins*, most numerous in regions where the ice was thickest and abrasion most active; and (2) *drift basins*, most numerous in regions of glacial melting and deposition of drift. The great moraine systems which stretch across the United States from Cape

Cod to the Dakotas, and across Europe from the Valdai Hills to Denmark, are belts of small lakes. Morainic basins due to the irregular deposition of drift are extremely variable in form, but may be classified as *kettle*, *channel*, and *irregular* basins.

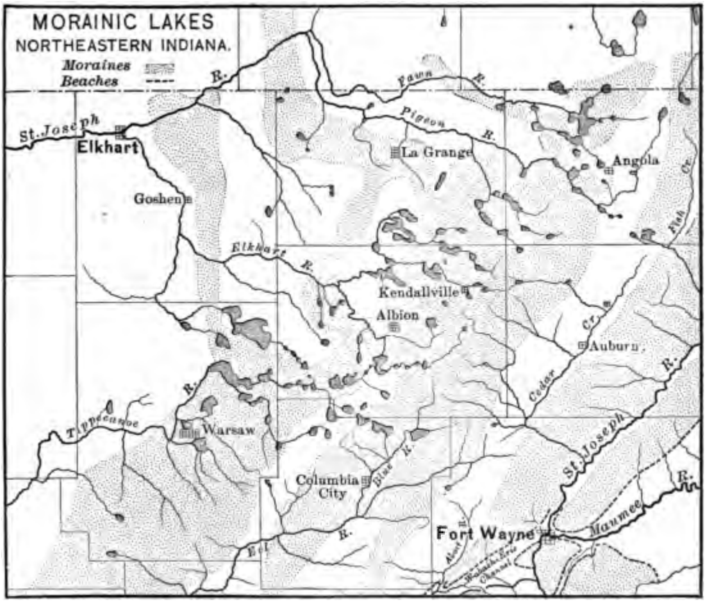


Fig. 103.

Kettle basins or *kettle holes* (Fig. 92) are roundish, caldron-, or funnel-shaped depressions which owe their existence to the melting of detached masses of ice left, during the glacial retreat, partly buried in drift. Those which have a clay bottom are filled with water, but those with a gravel bottom are generally dry. *Channel* basins are long and narrow, and were made by streams which temporarily drained the melting ice front. *Irregular* basins are combinations of kettle holes, channels, and other depressions which fill and overflow into one another, forming connected bodies of water at the same level.

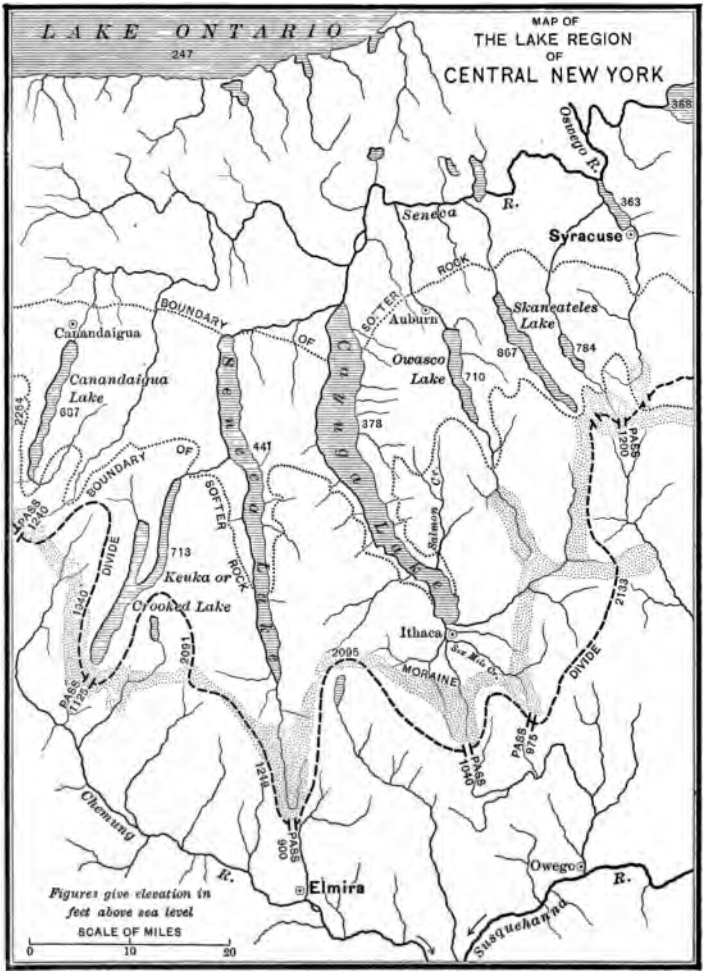


Fig 104.

The Finger Lakes.—Glaciated regions abound in long, *narrow rock* basins occupied by lakes, among which those

in central New York called, on account of their form and relative positions, the Finger Lakes, are of peculiar interest.

The northern slope of the Alleghany plateau is here trenched by many long, narrow valleys from 1000 to 2500 feet deep, some of which contain lakes, while many do not. Of larger and smaller lakes there are more than a dozen. Seneca and Cayuga are each about forty miles long and one to three miles wide. Seneca is 441 feet above sea level and 618 feet deep. Cayuga has an elevation of 378 feet and a depth of 435 feet. On the plateau between the lakes tributary streams flow in broad, shallow valleys until within a short distance of the lake, where the valleys end in the air, as if cut off (Fig. 106), and the streams drop into deep, narrow gorges which continue almost to the lake shore. Small deltas and alluvial terraces occur at various elevations on the hillsides.

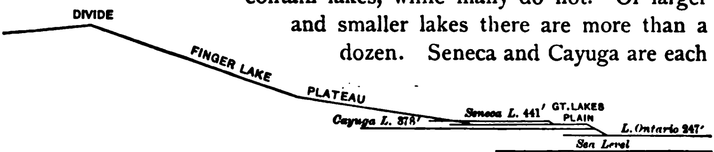


Fig. 105.—Profile of northward slope of Finger Lake plateau.

Fig. 106.—**Taughannock Falls, near Cayuga Lake.**

The Finger Lakes occupy basins which were in preglacial times the valleys of streams flowing into the Ontario basin. When the ice sheet moved from the north over this region it was comparatively thin on the ridges, but much thicker in the valleys. By glacial abrasion the valleys were widened and deepened, and the slopes on either side made more steep. During the

retreat of the ice the ridges were probably uncovered first, while considerable masses of ice still occupied the valleys. As the ice gradually melted and the lake surfaces fell from one level to another, the tributary streams on the plateau entered the lakes at different levels, forming deltas and terraces which they afterward cut through or abandoned, building others at lower levels. The lake basins had been so much deepened by glacial erosion that the old tributary valleys were left far above the present lake levels, and the streams, compelled to cascade down the steep slopes, began to cut back their present gorges or glens.

Fig. 107. — Cross section of Cayuga Lake valley.
(Vertical and horizontal scales the same.)

The Cayuga basin was probably made 350 to 450 feet deeper by ice abrasion; but the valley is still only a broad, shallow groove.

Mountain Valley Basins. — The Alps and other mountain regions which have been recently glaciated contain many basins similar in essential characteristics to those of the Finger Lakes. The valleys head in vast cirques or amphitheaters upon the flanks of the mountains, the sites of former névé fields, whence they descend by irregular steps through successive basins to the lowest, which lies near the end of the old glacier and sometimes extends out into the surrounding plain. The lower ends of these basins are usually bordered by morainic dams. The Italian lakes, Como, Lugano, Garda, and Maggiore, and the Swiss lakes, Geneva, Constance, Zürich, and Lucerne, occupy basins of this kind. Landslips, moraines, and deposits of sediment by lateral streams have built the natural dams which hold back the waters of many mountain lakes, but their basins are due largely to glacial erosion. Such mountain lakes are numerous in Scotland, Scandinavia, New Zealand, and the Rocky Mountains.

The Scotch highlands have been subjected to very extensive glacial erosion, and contain numerous lakes, of which Loch Katrine is one of the most beautiful. Its length is eight miles, its width one mile, and its depth 495 feet. It fills a single symmetrical basin which is closed at its lower end by a belt of very hard and durable rocks. During the later stages of the glacial period the direction of ice movement was down the valley, which was scooped out to a depth of 130 feet below sea level; but the more resistant rocks were left as a barrier which holds the water up to its present level.

Fig. 108. – Loch Katrine.

The Laurentian Lakes. — Of special importance, on account of their great size and interesting history, are the Great Lakes of the St. Lawrence system. Lake Superior is the largest body of fresh water on the globe, and it contains 280 of the 570 cubic miles of water stored in this chain of reservoirs.

Their areas, levels, and depths are given in the following table: —

	Area in sq. mi.	Elevation, ft. above sea level.	Maximum depth in feet.	Average depth in feet.
Superior	31,200	602	1,008	475
Huron	23,800	581	730	250
Michigan	22,450	581	870	325
Erie	9,960	573	210	70
Ontario	7,240	247	738	300

They occupy a series of comparatively elongated basins, separated by small areas of land, and joined near their ends by short streams or straits. The shape of the lakes, their nearness to one another, their end connections,

and their trend suggest an overgrown stream line with a succession of immense reaches, a repetition on a grand scale of the characteristics of almost any meadow brook. They occupy basins which seem to be the broken and obstructed sections of a great stream valley. This impression is strengthened by the course of the line of greatest depth, as shown by the heavy line in Fig. 109. The bottoms of all the lakes except Erie are below sea level.

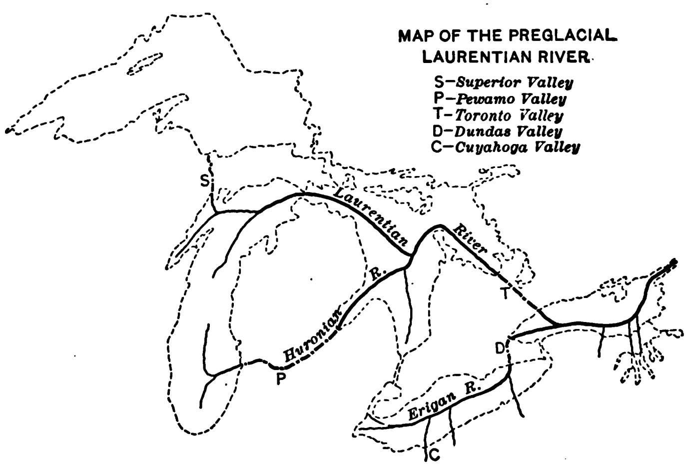


Fig. 109.

Evidences of Glaciation. — The whole St. Lawrence basin was deeply buried under the ice sheet, evidences of which are abundant in the grooved and scored rock surfaces on the islands and shores of the lakes, in the lobed and irregular shape of their southern shores, and in the arrangement of the terminal moraines of the glacial lobes around and between them (see map, p. 125).

Evidences of Tilting. — The lake basins are surrounded by numerous old beaches or shore lines, which mark the height and limits which their waters have at some time reached. But these old shore lines are no longer level. They gradually rise toward the north and east. One of them, known as the Algonquin beach, is 25 feet above the southern

end of Lake Huron, and 635 feet above its northern end. The depth of the lakes below sea level, and the extensive drowning of the St. Lawrence valley (see p. 95), show that the whole basin once stood at a considerably higher level than at present; while the occurrence of bones of the whale and other marine animals along the shores of Lake Ontario and Lake Champlain shows that these lakes and the lower St. Lawrence valley once formed a great arm of the sea, an extension of the Gulf of St. Lawrence. All these facts point to the conclusion that the basin of the St. Lawrence has been subjected in the past to extensive depression and upheaval, which was in the nature of a tilting along a northeast and southwest line.

Many of the peculiarities of the basins of the Great Lakes may be attributed to the agency of the Laurentide ice sheet, which, creeping forward from the Canadian highlands, flowed into, filled, and crossed these basins. The preglacial valley of the Laurentian river was probably widened and deepened in some parts by the removal of material, and obstructed in other places by its deposition. Borings have revealed many deep valleys which lead into or connect the lakes, but are now filled with drift. Among these are the Pewamo or Grand River valley across Michigan, the Toronto valley between Georgian Bay and Lake Ontario, the Dundas valley between Erie and Ontario, and the valley of the Cuyahoga at Cleveland (see Fig. 109). The slight depth of Lake Erie indicates that its basin was not a part of the main valley, but a tributary to it.

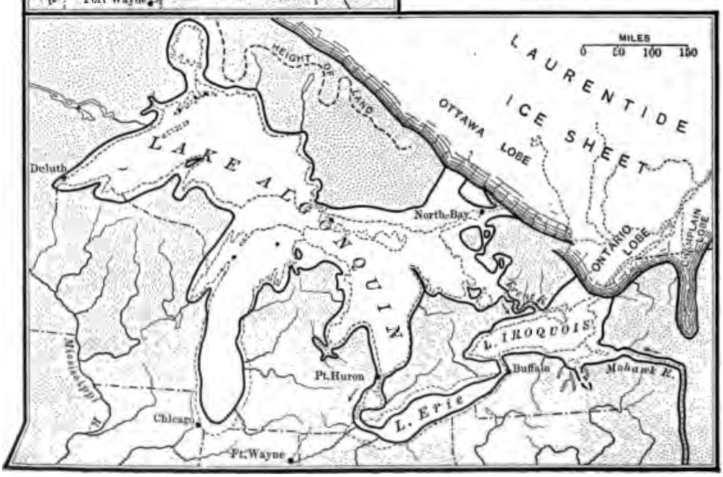
With the exception of Lake Superior, which is an old diastrophic basin, the Great Lakes are old river valleys, first cut wide and deep by weathering and stream erosion, then depressed, uplifted, and tilted by movements of the earth-crust, and finally widened, deepened, and cleaned out here and choked up and obstructed there, by the North American ice sheet.

Ice-dammed Lakes.--When the ice sheet began to melt away, and the southern divide of the Laurentian basin was uncovered, the water

collected at several points along the ice front and formed a number of temporary lakes of varied and changing size and form. They were bounded and held in on the north by the wall of the retreating ice front, but their outlines and outlets can still be traced by the beaches formed where their waves beat against the land. Figure 110 shows three out of the many successive stages in the long and complicated history of the Laurentian lakes.

Lake Agassiz. — The largest of the ice-dammed lakes of the period of glacial recession occupied the basin of Red River in Minnesota and North Dakota and extended far north-

Fig. 110.



ward into Canada (see map, p. 125). Its outlet was through the Minnesota River into the Mississippi, but the opening of an outlet through the Nelson River into Hudson Bay drained its waters until only Lakes Winnipeg and Winnipegosis remain. Its sediments now form the soil of the great wheat fields of the Red River region.

Barrier Basins

Many examples have already been cited of basins which are partly due to the formation of natural dams or bar-

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Fig. 111. — A barrier basin.
(Lake McDonald, in the Rocky Mountains, Mont.)

riers across a valley. There are few lakes which do not owe their existence, more or less, to this cause. The dam may be of hard rock, as in Loch Katrine; of glacial drift, as in the Great Lakes; or a terminal moraine, as in the case of mountain lakes. A lava stream from

a volcano sometimes obstructs a valley and forms a *coulée* lake. Landslides often form temporary dams, behind which water accumulates for a time and then breaks through with destructive violence. The deposit of a tributary stream may set back the waters of the main trunk into which it flows. The growth of coral reefs and the formation of sand bars result in the cutting off of portions of a sea or lake from the main body of water.

Fig. 112. — Intermorainic lakes, Idaho.

Thus shore lagoons of great variety and extent are produced. Probably glacial moraines act more often as barriers to drainage than any other species of dam. Wherever they occur in series, the valleys between usually contain many *intermorainic* lakes.

Other Basins

Volcanic Basins. — Crater Lake, in southern Oregon, is circular in form, with a diameter of five miles and a depth of 2000 feet. Its surface is 6239 feet above sea level, and it is bordered all around by precipitous cliffs from 500 to 2200 feet high. From the crest of the encircling rim the country slopes away on all sides. The roughly bedded layers of rock also slope outward and downward from the lake shores. The lake, as its name suggests, occupies the crater of an extinct volcano. The angle of its slopes indicates that its summit may have been a mile above the present lake surface. The material which once

Fig. 113. — Crater Lake, Oregon.

formed the cone and filled the crater was probably not blown out by an explosion, but has disappeared by sinking into the depths from which it came. Basins of this kind are not numerous, but Lakes Albano and Averno in Italy, the Laacher See in Germany, and Lake Taupo in New Zealand belong to this class.

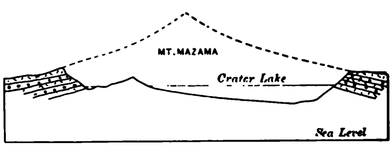


Fig. 114. — Crater Lake, Oregon.

Alluvial Basins. — The oxbow or horseshoe lakes, very common in flood plain regions, result from the cutting off of a river bend and the silting up of its ends. They have been fully discussed in connection with the Mississippi River.

Basins by Solution. — In regions of limestone rocks, where subterranean drainage channels exist, the falling in of the roof of a cavern often forms a sinkhole basin which partly fills with water. Deep pits or wells are sometimes formed by the escape of water through beds of salt, gypsum, or other soluble rock. This is the origin of many of the small lakes in Florida.

The Relation of Lakes to Rainfall and Drainage. — The existence of a lake in any basin depends upon the amount of rainfall, which must exceed the amount of water removed by percolation and evaporation. In arid regions the rainfall is generally insufficient to fill the basins to overflowing, the minerals brought in by tributary streams accumulate, and the water becomes salt or alkaline. Such lakes may dry up or fill with mineral deposits, leaving thick beds of salt, soda, borax, gypsum, or tufa; but on account of the absence of outlet streams which would cut down the rim, such basins are relatively permanent. In regions of abundant rainfall, lakes regulate the flow of outlet streams, preventing floods. They also act as settling basins for sediment, so that a stream flowing out of a lake is usually clear.

Of all features of the landscape, lakes are the most ephemeral. A combination of agencies is at work toward their speedy destruction. The inflowing streams are filling them with sediment and minerals deposited from solution, while the outflowing streams are cutting deeper channels through the retaining barriers. In the case of small, shallow lakes the growth of vegetation is one of the most efficient agents of destruction. Aquatic plants find anchorage and rich soil in the lake bottom, while they absorb the greater bulk of their food from the atmosphere. They grow and decay year after year, and the lake becomes filled with vegetable matter. Thus it is gradually converted into a peat bog or a muck meadow. A lake may be buried by the accumulation of vegetable matter which floats upon its surface. A large majority of lakes occur in glaciated plains, or in rugged mountain regions; that is, upon land surfaces which have not been long exposed to atmospheric agencies. They are characteristic of

the youthful stages in the development of relief. The lakes of arid regions are no exception to this rule, because erosion and deposition go on there with extreme slowness.

Realistic Exercises. — The student should make a list of all the agents and processes concerned in the formation of lake basins and classify the basins according to their origin. The topics to be considered in summary and review are: the most efficient agents in basin formation, the relation of lakes to climate, to rivers, and to the development of relief, and the general absence of lakes from old mountain regions like the southern Appalachians, and from extensive plains like southern Russia and southeastern United States.

The formation of basins and some of the characteristics of lakes may be studied in any locality, at least on a small scale. Any lake, pond, or pool exhibits some of the phenomena and processes peculiar to the life history of a lake, just as a small brook has many of the characteristics of a large river. Let the student investigate the origin of the basin, whether it be by excavation or damming or both. Inflowing streams are filling the basin with sediment and, perhaps, building deltas at their mouths. The outlet stream is usually clear, but may be cutting its channel deeper and lowering the water level. This lowering may be hastened by an artificial ditch. Low, level, and marshy land about the borders of the lake shows the former extent of the basin and the amount of filling which has taken place. Old beaches or shore lines may be found at some distance from the water's edge. The growth of vegetation may be noted, and the formation of peat around the shores. A temporary pool or puddle of water formed during wet weather and disappearing in a few days often furnishes an opportunity for the study of shore lines at successively lower levels, either cut into the face of a little cliff or built up where the shore is shelving. When it dries up, the fine mud brought in by feeding streams is left as a coating on the bottom and hardens into a genuine *playa*.


Fig. 115. — Shore lines on gravel bank.

CHAPTER XII

THE DEVELOPMENT OF DRAINAGE SYSTEMS

The Life History of a River. — By the action of running water the face of the land is being carved into ever-changing patterns of relief. While this work is going on, the streams themselves undergo a parallel series of changes. Every stream system has its life history, during which it develops from a stage of youthfulness, when it has just begun the task before it, through maturity toward old age, when its possible work upon the land has been accomplished. From a study of existing streams we may picture to ourselves an ideal river which passes through this series of changes without accident or interruption.

For the simplest case, suppose a considerable area of the earth-crust to be slowly elevated above the sea. Let it be composed of rock strata originally in a nearly horizontal position ; but suppose the strata, while in the process of elevation, to be somewhat crumpled and folded, forming a long ridge from which the surface slopes toward the sea in opposite directions. The result of this movement is a coastal plain, rising gradually into a plateau and then more steeply to a dividing ridge. The surface is slightly irregular, diversified by broad, shallow basins or elongated depressions, with broad, flat divides.

This newborn land is exposed to a temperate climate and a moderate rainfall. Weather and running water begin their work at once.

The run-off is at first in sheets rather than in streams. *Each basin is filled* until the water runs over into the next

lower one, and each long depression transmits a shallow flood until continuous lines of waterway are established from the high land to the sea. A waterway whose course is determined by the original irregularities of the surface of its basin, is called a *consequent* stream. The waters charged with sediment begin to corrade the surface over which they flow, and soon engrave it with delicate channel lines. The valleys contain numerous lakes, but extend in the general direction of the steepest slopes to the sea. Each stream has its steepest slope near the divide, but its volume there is small because it drains a small area. Near the sea it has a large volume but a gentle slope. Therefore the middle portion, having the requisite volume and swiftness, intrenches itself most rapidly.

At first each drainage line is an almost limbless trunk, but as it sinks its channel deeper into the earth-crust, the lakes are drained and lateral branches appear which traverse the intervals between the main streams. As the main stream deepens its channel its branches are given a steeper slope, their currents are quickened, and they develop other branches as the main stream has done.

Thus the drainage system grows by extending its branches upward and outward like a tree, until their tips reach the crest of the main ridge and interlock with the tips of the branches of the next system on either side. Water falling upon any portion of this land finds a system of continuous channels by which it returns to the sea, and the drainage is complete.

In the middle portion of a river, where corrasion is most rapid, a larger number of strata are cut through, some of which prove to be harder and some softer: consequently rapids and cataracts appear which retreat upstream, leaving gorges below them. On account of the disturbed and

crumpled condition of the rock strata in the highest ridge, alternations of hard and soft layers are frequent, and the head waters present a series of cascades which persist a long time because the streams are too small to wear the strata away.

In the lower reaches of a river the valley is soon cut down to *base level*, where the slope is gentle and the current too slow to carry the full load of sediment it receives. Deposition occurs and downward corrasion ceases. The stream begins to swing from side to side, to undermine its bluffs, and thus to widen its valley. Floods are frequent, and spread over the wide valley floor their successive layers of sand and mud. Thus a wide flood plain is built up and becomes characteristic of this part of the river's course.

Meanwhile the river may be depositing a delta at its mouth and pushing it out to sea, and thus building a dam of sediment. The base-leveled and flood-plain condition gradually extends itself up the main stream and thence up the larger tributaries in succession, until at length corrasion and valley deepening continue only in the torrential head waters and in the middle portion, where it is less vigorous than at first.

The head-water streams are small in volume, and the load they carry is the coarsest, but they are able to move it because of their steep slopes. In the middle course the load of sediment gathered by the tributary streams is large, but in its descent from the upper valleys it has been ground finer. The volume of water is larger and its flow is sufficiently swift to enable it to carry its greater load. In the lower course the load is still larger and finer, but the volume of water is proportionately great, and through all its writhings and shiftings the river staggers on, dropping sediment here and now, and picking it up again there and hereafter, but in the long run getting it delivered finally to the sea.

A river which has acquired a perfect adjustment between its volume, slope, and load is said to be a *mature, graded* stream. It is a condition toward which all streams *are tending*, but which few ever reach. By their degree

of approach to it, not by years, is their age reckoned. A man at twenty years is young, but a horse of twenty is old, not in time, but in stage of development.

If a stream system should ever reach base level throughout the extent of its trunk and principal branches, and should reduce its basin to a plain faintly sloping from low, indefinite divides to wide flood plains, it would have reached a condition of *old age*.

The Development of Valleys. — By downward corrasion a stream cuts a steep-sided trench of its own width, but weathering, gravitation, and the wash of the rain widen it and make the sides sloping. The form of the valley in cross section varies with the stage of development, and with the material into which it is cut. A very young valley is a simple V-shaped groove, as may be seen in any hillside gully. As time goes on, it becomes deeper and more flaring,

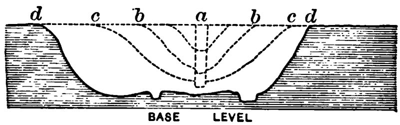


Fig. 116.

as shown in *b* and *c*, Fig. 116. When base level is reached, and the valley passes into a flood-plain condition, the form is radically changed, as in *d*. If the walls of the valley contain strata of unequal hardness, the form is modified by the projection of hard layers and the retreat of the softer ones, as shown in Fig. 117. If the strata are not horizontal, various unsymmetrical forms are produced, as in Fig. 118.

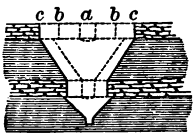


Fig. 117.

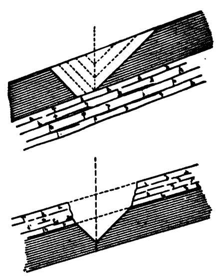


Fig. 118.

The Development of Divides and Profiles. — The divides and ridges between stream valleys pass through a corre-

sponding series of changes. They are at first broad and flat or gently rounded, as *a–a*, Fig. 119. As the valleys widen, the interstream ridges grow narrower and sharper and are finally lowered. A slope made irregular by weathering is steeper in hard material and more gentle in soft, and the tendency of water running over it is to wear away the projecting corners, where the flow is swiftest, more rapidly than the reëntrant angles, where the flow is slowest. The tendency also is to leave only the coarse sediment near the top of the slope and to spread the finer far out from its foot (Fig. 120). It follows from these conditions that slopes produced by weathering tend to be irregular, that a perfectly graded slope grows steeper toward the top, and that *its profile is a curve concave upward, with the greatest curvature at the upper end.* This is called the *curve of corrasion or stream erosion* (Fig. 121).

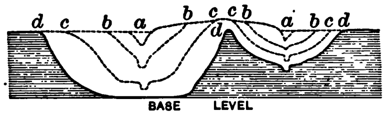


Fig. 119.

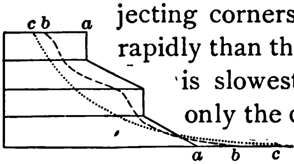


Fig. 120.

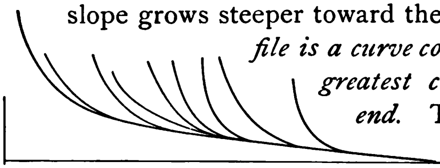


Fig. 121. — Curves of corrasion in a stream and its tributaries.

A graded slope is usually flattened at the top, where the rivulets run only while it rains and are too feeble to corrade. *The curve of rain-wash is convex upward.* The relative extent of these two curves depends mainly upon elevation. On high plateaus and mountains the curves are concave to the very top and the ridges are sharp and angular (*ABC*, Fig. 122). On hills and plains the curves are convex, and the elevations are broad and rounded (*BD*, Fig. 122). Combinations of the two curves exist in all proportions. *The progress of erosion tends toward the final flattening of all slopes.*

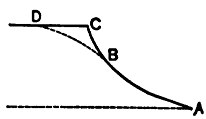


Fig. 122.

The Migration of Divides.— During the development of drainage systems a struggle goes on between adjacent trunk streams for possession of the territory. Some rivers, by reason of larger volume, steeper slope, or softer materials to work in, are able to extend their branches and head waters more rapidly than others, and thus to push back the divides and invade the basins of their neighbors. This may occur gradually by a general widening of the valley of the stronger stream, as shown in Fig. 119, or it may occur rather suddenly by *capture* or *piracy*.

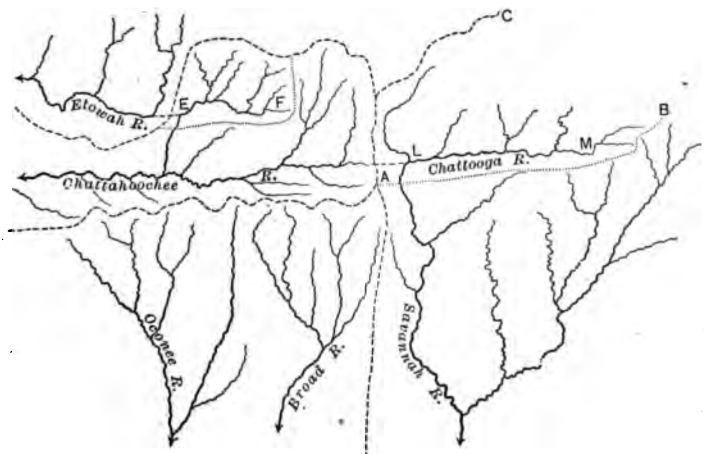


Fig. 123.

The Chattooga River, at the western corner of South Carolina, was formerly the upper part of the Chattahoochee ; but the Savannah had a shorter course to the sea and a more rapid fall. One of its tributaries was able to extend itself until it tapped the Chattahoochee and robbed it of its head waters *LM* (Fig. 123). The divide was thus shifted from the line *AB* to the line *AC*. The Oconee will probably repeat this process in the near future. An elbow or right angle in the general course of a river is frequently an indication that it has thus beheaded one of its neighbors, as at *E*.

The St. Joseph River in southern Michigan was originally the upper part of the Kankakee in Indiana. While the edge of the Michigan ice lobe stood along the terminal moraine, a large stream now represented by the Dowagiac drained the ice front and emptied into the Kankakee at the site of South Bend. When the ice withdrew, the Dowagiac turned aside through a gap in the moraine to the basin of Lake Michigan. A portion of its channel was thus abandoned by the main stream and left to transmit in a reversed direction a small tributary. This tributary had a fall of more than three feet to the mile, while the Kankakee had only one third as much; and it did not take very long for the more rapid stream to eat back the low divide at its head, and to divert the St. Joseph from the Kankakee and Mississippi to Lake Michigan and the St. Lawrence.

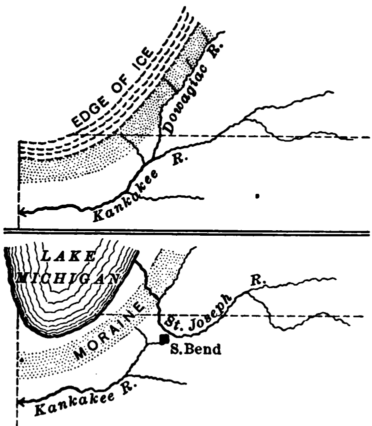


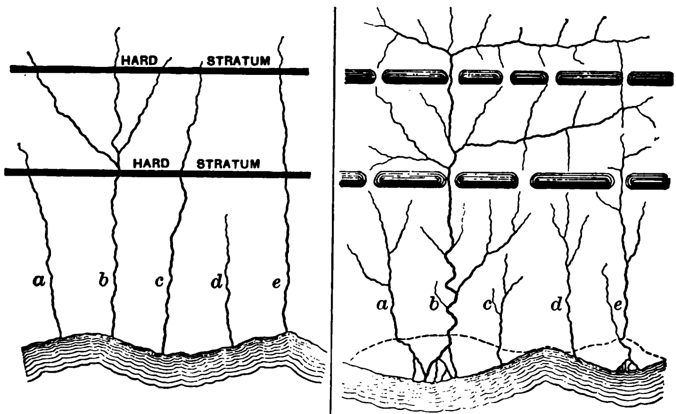
Fig. 124.

The Development of Meanders. — A straight stream is an impossibility in nature. The current through an artificial ditch soon shows a tendency to become crooked. A slight inequality in the firmness of the bank, or an accidental obstruction, is sufficient to turn the current to one side, from which it is deflected toward the other, and incipient meanders are established.

The course of a stream consequent upon the irregularities of a surface newly raised above the sea or renewed by glacial action is crooked in an irregular manner. As a stream continues its work it develops meanders according to its conditions. The steeper the slope and the swifter the current, the more direct is the course. As the stream

approaches base level the available energy is so reduced that a slight obstruction is sufficient to turn it aside, and it develops in its flood plain the wide curves so characteristic of large rivers (see maps of the Mississippi). These are roughly symmetrical because the material of the flood plain is nearly homogeneous.

Subsequent Streams. — As consequent streams deepen their channels they are liable to find differences in the hardness of the rock over which they flow, and are



A. Consequent drainage. *B*. Subsequent drainage, with water and wind gaps.

Fig. 125.

obliged to adjust themselves to these conditions. Suppose the young consequent streams shown in Fig. 125 *A* to flow down a moderate slope across which two strata of hard rock extend at right angles to the streams. The strongest stream (*b*) is able to cut gaps through the hard strata more rapidly than the weaker ones. It extends its branches to the right and left in the softer strata, and finally not only beheads its neighbors, but dismembers them, and adds their fragments to its own system, as

shown in Fig. 125 *B*. The branches which are developed in the softer strata are called *subsequent*.

The map of such a system looks like a grapevine trained upon a trellis, and it is hence called *trellised* drainage (Fig. 125 *B*). Where the main stream crosses the softer strata, weathering and lateral corrasion are most rapid, and the valley is wide and open; but its level can not be sunk lower than that of the stream where it cuts through the hard stratum below. Each hard stratum acts as a dam which determines the base level of the stream above. In this dam the river slowly cuts a narrow notch, which, in the progress of erosion, becomes a sluice or gateway through a ridge standing out above the level of the more easily eroded country on either side. Such a gateway is called a *water gap* (see Fig. 159). The shallower notches made by the other streams before they were dismembered, and now abandoned, remain as *wind gaps*.

Disturbances of Stream Development. — It is very seldom, if ever, that a stream is permitted to pass through all the stages of development from youth to old age in a regular and normal manner. The most important interruptions arise from elevation or subsidence of the stream basin and from glaciation. The general effect of elevation is to put new life and vigor into a stream by giving it a steeper slope. It begins over again the work of deepening its valley and extending its head waters.

Thus a new set of narrower, deeper, and straighter waterways are cut down into the floors of the old ones, and rocky shelves or terraces are left to mark the old valley floors (see Figs. 51, 52). Subsidence has an effect the reverse of that due to elevation and makes a stream prematurely old. Its slopes are diminished, its current slackens, the lower portion of its valley is drowned, the middle portion fills up with sediment, and only the head waters are able to continue actively the work of corrasion. Changes of climate which increase or diminish the rainfall have a corresponding effect upon the volume and force of streams.

Glaciation. — Some of the effects of glaciation upon streams have already been noticed. During the existence of an ice sheet nearly all the streams in the glaciated

region are temporarily obliterated, and after its disappearance their courses are found to be permanently diverted, or their valleys dammed and choked with drift.

Fig. 126. — Alluvial terraces.
(Mississippi valley, near St. Cloud, Minn.)

Many of the valleys which drained the ice front were flooded with water and half filled with sand and gravel. Since the disappearance of the ice the diminished streams have been at work cleaning out their old valleys, with imperfect success. In most cases, the stream has cut a new and smaller channel through the drift filling, leaving massive alluvial terraces on either side.

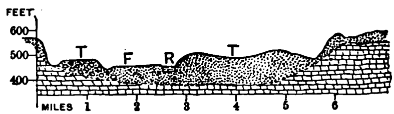


Fig. 127. — Cross section of a filled valley.
(*T*, terrace; *R*, river; *F*, flood plain.)

Summary. — A *young* stream is one which has accomplished but little of the work of erosion and degradation of the land which is possible for it to do. It is characterized by irregular profile, steep slope, swift current, narrow valley, and numerous rapids, cataracts, and sometimes lakes. The Colorado River is an extraordinary example of a young river. The St. Lawrence, once a mature stream, has been *rejuvenated*, or restored to infancy, by glaciation.

A *mature* stream is one which is well advanced in the work before it. It has graded or nearly graded its valley, and its profile is nearly the ideal curve of corrasion (see Fig. 121). Its valley is broad and its lower portion is in the flood-plain condition. The rapids, cataracts, and lakes have disappeared or linger only along the head waters. The Mississippi river system has nearly reached the stage of maturity.

An *old* stream is one which has reduced its basin to the lowest possible level. It would resemble the lower Mississippi; but there is probably not a river in the world which has reached that stage throughout. Rivers are seldom permitted to reach old age, but are either drowned by the sea or restored to youth by the accidents of upheaval or glaciation.

A *consequent* stream is one whose course is determined by the relief of the surface of its basin. All streams are at first consequent.

A *subsequent* stream is one which does not appear in the youthful stage of a system, but is developed later as a branch, usually along a line of softer rocks.

An *antecedent* stream is one which has maintained its original consequent course in spite of upheavals of the land and the growth of plateaus and mountain ranges in its basin. Some portions at least of the Green-Colorado system are antecedent.

A *superimposed* stream is one whose course has been determined by the relief of some previously existing surface, which has been removed or greatly modified by erosion. Its course, like that of an antecedent stream, has little or no relation to the present relief. When the consequent streams of the glacial drift have swept it away and laid bare the surface of the bed rock beneath, they

will become superimposed. Some portions of the Green-Colorado may have been superimposed from a surface which has since been removed by degradation. The Susquehanna, Delaware, and Potomac are superimposed streams (see pp. 185, 186).

Streams as Factors in Human Life. — *Drainage.* — The natural function of streams is drainage. They carry away the surplus water supplied by rainfall, in excess of that which is evaporated. Most of the ground-water finally reaches the streams. Drainage is most rapid and complete where the slopes are steep, the surface compact, and vegetation scanty. In mountainous regions generally these conditions prevail in a high degree, the rainfall runs off quickly, and the streams are subject to great variations in volume, being flooded during a storm, and nearly dry in clear weather. The removal of forests and the cultivation of the ground render drainage more rapid and complete. More rapid run-off carries away greater loads of mantle rock, and hastens the process of stream erosion. In some cases, the destruction of forests has resulted in washing away the soil and leaving the surface barren and worthless. On the other hand, slow and imperfect drainage may be as objectionable as too rapid drainage. A region which is imperfectly drained abounds in marshes, ponds, and lakes, which support a vegetable and animal life peculiar to themselves. Such regions are comparatively unfavorable for human occupation until their drainage is artificially improved. The cutting of ditches and the laying of underdrains may remove the stagnant water, and render the rich accumulations of *humus*, or decayed vegetable matter, available for the growth of agricultural plants. Some of the best areas for farming and gardening have been obtained in this way.

Flood plains. — The most productive lands in the world are flood plains. At every period of high water, a stream brings down mantle rock from the higher grounds, and deposits it as a layer of fine sediment over its flood plain. A soil thus frequently enriched and renewed is literally inexhaustible. In a rough, hilly, or mountainous country, the finest farms and the densest population are found on the "bottom lands" along the streams. The flood plain most famous in history is that of the river Nile in Egypt. For a distance of 1500 miles above its mouth this river flows through a rainless desert, and has no tributary. The heavy spring rains which fall upon the highlands about its sources produce in summer a rise of the water, which overflows the valley on either side. Thus the lower Nile valley became one of the earliest centers of civilization, and has supported a dense population for 7000 years. The conditions in Mesopotamia, along the Tigris and Euphrates rivers, are similar to those along the lower Nile, and in ancient times this region was the seat of a civilization perhaps older than that of Egypt. The flood plains of the Ganges in India, and the Hoang in China, are the most extensive in the world, and in modern times the most populous. The alluvial valley of the Mississippi is extremely productive of corn, cotton, and sugar cane.

Irrigation. — In all ages the extent and value of flood plains have been increased by artificial means. Dikes or levees are built to regulate the spread and flow of the water and to protect the land from destructive floods. Dams and reservoirs are constructed for the storage of water, which is led by a system of canals and ditches to irrigate large tracts of land which would be otherwise worthless. By means of irrigation, the farmer has control

of his water supply and is able to get larger returns than are possible where he depends upon the irregular and uncertain rainfall. It is estimated that in the arid regions of western United States there are 150,000 square miles of land which may be made available for agriculture by irrigation. Perhaps in the future the valley of the lower Colorado may become as productive as that of the Nile.

Routes of travel and commerce. — Streams are the easiest routes of travel and commerce. In uncivilized countries they are almost the only ones. Explorers take advantage of them to penetrate the interior from the sea, and the first settlers follow the same routes. A river usually furnishes from its mouth well up toward its source a smooth, graded highway, upon which a cargo may be transported with much less effort than overland. If obstructions occur in the form of rapids or falls, boat and cargo are carried around them. It is often easy to pass by a short portage or "carry" from one stream system across the divide to another. In a new country, homesteads, towns, and cities spring up first along the streams, and the density of population and the value of land decrease back toward the divides. As the country becomes more thickly settled, wagon roads and railroads are built, and the waterways become less important. But in regions which are not very level the easiest grades in every direction are found along the streams, and the main routes of land travel follow the stream valleys. In traversing a mountainous region, a railroad follows the windings of some river up to the crest of the divide, which it crosses through a pass, or often by a tunnel, and descends the valley of some stream on the other side.

If a stream is too shallow or too much obstructed for easy navigation, a canal may be built either around

the obstructions or through the whole length of the valley. In the most highly developed countries the large rivers still form highways of commerce. Their mouths furnish good harbors for sea-going vessels, and lighter craft can penetrate far inland. The Mississippi is navigable to St. Paul, 1000 miles from the sea, and the St. Lawrence with the Great Lakes carries more tons of freight than any other inland route in the world.

Water power, etc. — Streams with rapid fall furnish water power available for running machinery. Regions where such streams are numerous and accessible, as in New England, furnish unusual facilities for manufacture, and the country becomes densely populated. A fall or rapid upon any stream is likely to become the site of a manufacturing and commercial center. The water power at the Falls of Niagara, now partly utilized, is sufficient to run all the machinery in several of the largest cities on the continent.

Thus, by furnishing easy routes for transportation, and cheap power for manufacturing, rivers have determined the principal lines of human travel and migration, and the principal centers of human settlement. Nearly all the large cities of the world, and thousands of smaller ones, owe their location and growth to the advantages furnished by some stream.

Streams furnish a supply of fish and other animals valuable for food or clothing. Uncivilized peoples often depend upon them mainly for support, and in cases like that of the salmon of the Columbia and other streams of the Pacific slope, fish become an important article of commerce. Streams have trenched their valleys into the crust of the earth and exposed the bed rock, which is thus made accessible to the quarryman.

Sources of knowledge. — The long and often deep sections cut by streams enable us to observe the structure of the earth-crust, and to read its history. In this respect no other river has done so much for us as the Colorado. In its canyons the layers of stratified rock are exposed down to the granite core of the earth, and we have been able to interpret there the story of the past, and to learn the processes by which the various forms and features of the land have been produced.

Beauty of scenery. — Man is largely indebted to streams for the variety and beauty of scenery. Running water itself is attractive to young and old. A landscape without water lacks its chief charm. A child instinctively finds its way to the brook, and the man seeks beside the river the pleasure and recreation which no other place affords. Streams have carved the surface of the land into an endless variety of beautiful forms, and a land where stream valleys are few or shallow is monotonous and tiresome. The most common as well as the most celebrated beauty of scenery in the world, from the tiny meanders of a meadow brook to the unequaled grandeur of the Colorado canyons, is largely due to the presence and action of streams.

CHAPTER XIII

FORMS OF SEDIMENTATION

Run-off of Mantle Rock. — There is not only a constant run-off of water from the face of the land, but also a run-off of the land itself, and the two are closely connected. A snow field accumulates by additions at the top until an ice sheet is formed which escapes down a valley or spreads over a large part of a continent. A sheet of mantle rock grows by progressively deeper weathering of the bed rock at the bottom. If it rests upon a nearly level surface it may remain where it was formed and constitute a *residual soil;* but if formed upon a slope, it creeps downward. On very steep slopes enormous masses of earth sometimes slip suddenly, forming a *landslide* analogous to an avalanche of snow.

Fig. 128. — A landslide.
(Sawtooth Mountains, Ida.)

Gravity is the chief agent, but it is assisted by the forces of freezing and thawing. The movement is most rapid along the face of a vertical cliff, from which fragments fall by their own weight and form a *talus* with a slope as steep as the character of the material will permit.

Wind Deposits. — The wind is an important factor in the movement of mantle rock, transferring it up grade as well as down. Along the shores of the sea and of large lakes, the winds from the water blow the sand up

Fig. 129. — Talus slopes.
(Devils Lake, Rocky Mountains.)

in wavelike heaps which resemble the sand ripples in the bottom of a stream, sweeping it up the long slope to the crest and dropping it over the other side. Thus the *dune* (Fig. 131), as it is called, travels slowly inland and buries forests and farms which may lie in its way.

Fig. 130. — Sand ripples.
(Algerian Sahara.)

The most extensive dune systems are found in desert regions, where the sand is continually passing through a series of shifting forms like the waves of the sea. The loess which occurs so plentifully in connection with the glacial drift (see p. 124) is thought by some to be, at least in part, a wind deposit.

Glacial Drift.—The agency of ice in the transportation and removal of mantle rock has already been discussed in detail (see Chapters IX and X). Drift sheets and plains, moraines and drumlins, are forms assumed by mantle rock on its way to the sea when deposited by ice.

Fig. 131.—Sand dune on the shore of Lake Michigan.

Kames and eskers are similar forms which are produced by the combined action of ice and water. When a glacier reaches the sea a portion of its load is floated away by the icebergs and distributed over the sea bottom as they melt. Ten pounds of ice is sufficient to float one pound of rock.

Alluvial Deposits.—The movement of mantle rock would be very sluggish indeed if it were not for the fact that with the help of running water the rock assumes a condition in which it is virtually liquid. Suspended in water the sediment is transported according to the laws explained in Chapter IV.

A slight decrease in the velocity of a stream greatly diminishes its power to carry sediment. The coarsest part of its load is dropped first, and afterwards the finer parts. Running water thus has a remarkable power of assorting materials. If its velocity is gradually and continuously checked there is a continuous deposit of sedi-

ment, varying downstream from coarser to finer. If its velocity is suddenly checked, coarse and fine sediments are deposited together without much assorting. As the volume and velocity of a stream vary at any given place, it may deposit there at different times coarse or fine sediment or none at all. Thus alluvial deposits are always characterized by *stratification*, or division into more or less distinct layers. Each layer is made up of similar fragments, and represents a period of continuous deposition. Each division plane represents a pause in deposition, or an abrupt change in the character of the material.

Alluvial Cones and Fans. — A mountain stream with a very rapid fall brings down a mass of coarse débris, and at the foot of the slope, where

Fig. 132. — Alluvial cone.
(Near Salt Lake City, Utah.)

the current is suddenly checked, deposits it in the form of a steep *alluvial cone*. Where the sediment is finer it is spread out into a low, broad *alluvial fan*.

Alluvial Plains. — The alluvial plains formed in the lower courses of great rivers have already been described

(see pp. 74–78). In some cases a diastrophic valley may become filled with sediment to a great depth and be converted into an *alluvial plain*. One of the most extensive alluvial plains in the world is the valley of California, between the Sierra Nevada and the Coast Ranges. It is 400 miles long by 80 miles in width, and has been filled with sediment, brought mostly by the streams from the Sierra, to the depth of two thousand feet.

Lake basins which have been filled with sediment form *lacustrine plains*.

Deltas.— A delta differs from an alluvial fan in being a deposit in still water instead of on land. It is generally larger, broader, and flatter than a fan, but the two are not always easily distinguished. Any stream, large or small, flowing into a pond, lake, or sea, may build a delta if the conditions are favorable. Strong waves, tides, and currents in the receiving body are unfavorable conditions, but large rivers are able to accomplish the work in spite of them.

One of the largest deltas in the world, that of the Ganges-Brahmaputra, has been built in the Bay of Bengal where the tides rise and fall sixteen feet. Large deltas are but extensions of flood plains, and they grow more rapidly where the water off the mouth of the river is shallow. Their extension is often retarded by the fact that the crust of the earth slowly sinks under the load of sediment, as seems to be the case at the mouth of the Mississippi, where the deposit has acquired a vertical thickness of a thousand feet or more.

Coast Shelves. — Through whatever forms mantle rock may pass on its downward way, its final destination is the bottom of the sea. The streams of ice and water discharge it into the shallows along the shore, and the waves, tides, and currents help to distribute it over a wider belt. The coarser material is not carried far beyond the existing shore line, but the very finest may be lodged several

hundred miles out. Thus along the coast of every land mass the coast shelf is being built up at a rate which varies with the quantity of sediment and the depth of the water.

Deposits from Solution. — Another portion of the material carried from the land remains to be noticed. It is not mantle rock and it plays no part in the construction of the forms just described. Those mineral constituents of the earth-crust which are dissolved by rain water become actually liquid and their run-off is free and rapid. In the Mississippi River the quantity of mineral matter carried in solution forms more than one fourth of the whole amount discharged into the Gulf. It consists chiefly of carbonate and sulphate of lime and common salt.

Fig. 133. — Alkali plains, Arizona.

Ground-water is nearly everywhere charged with lime, salt, and other minerals in varying quantities, and wherever it evaporates from the surface of the earth a saline crust is slowly formed. Thus in dry regions the soil gradually becomes charged with "alkali," forming "alkali plains."

In lakes which have no outlet streams vast quantities of salts accumulate. Beds of rock salt hundreds of feet thick are of frequent occur-

rence in the earth-crust, and mark the sites of ancient lakes or seas which have dried up. Every stream delivers to the sea its quota of salts in solution, and sea water would grow indefinitely more salty if it were not for the agencies which bring about a partial deposit of its mineral matter.

Foremost among these agencies is animal life. Most of the animals and some plants which live in the sea have a shell or bony skeleton composed of lime which the animal or plant extracts from the water. When the organism dies the skeleton sinks to the bottom, and contributes to the formation of a lime deposit. Animals and plants thus convert the dissolved lime into an organic sediment which is subject to the same laws as any other sediment. One third of the sea bottom is covered with a soft gray ooze or mud made up entirely of the shells of minute animals which live in the surface waters. This deposit only needs consolidation to produce rocks resembling the chalk that is abundant in England and other parts of the world (see p. 33).

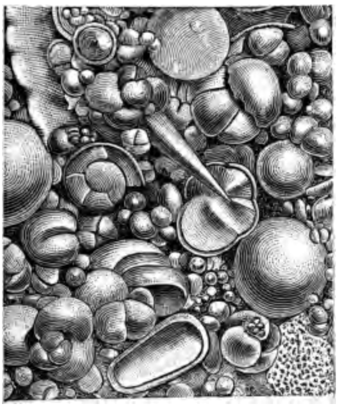


Fig. 134. — Ooze, magnified.

Coral Reefs. — The most peculiar and interesting accumulations of limestone in the sea are the coral reefs. The rock of coral reefs is chiefly made up of the skeletons of various species of the coral polyp. The individual polyp varies in size from a pinhead to a foot or more in diameter, but most of them are small. In the reef-building species the individuals are not free and separate, but thousands of them are connected together in one head or mass which is attached to the bottom and grows by branching out somewhat like a bush. The young polyp is produced by budding from the side of the parent, and remains attached to the parent stem. The combined group of individuals secretes a lime skeleton

which forms a foundation upon which new generations build, a head of coral being alive only at the tips of the branches. These animals flourish in warm, clear water where a strong current brings them plenty of food. They can not live in muddy water, or if exposed to the air, or at depths greater than about 300 feet.

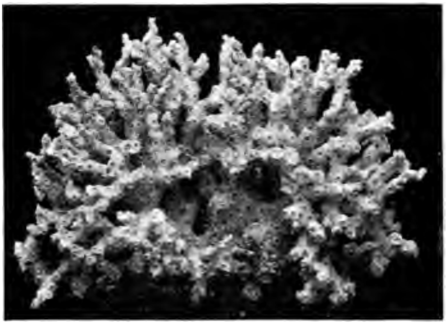


Fig. 135. — Branching coral.

The bottom of the sea is traversed by numerous ridges from which volcanic peaks rise nearly to the surface or project above it, forming small islands. The submerged peaks present conditions favorable to the growth and multiplication of myriads of sea animals, whose remains accumulate until a shoal or bank covered with shallow water is formed. Upon this foundation patches of coral begin to grow upward and to spread out as far as the shallow water extends. As the top of the patch approaches the surface of the sea (Fig. 136, *a*), the polyps near the center die from crowding, want of food, occasional exposure to the air, and the deposit of mud and sand, while those near the edges, having plenty of room, food, and clear water, continue to grow and extend outward (Fig. 136, *b*). The waves break off pieces of the living coral rock and pile them up on the reef until its edge is raised in some places five to fifteen feet above the sea. At the same time the water dissolves out the dead coral rock from the middle (Fig. 136, *c*). The result is an irregular, broken ring of land surround-

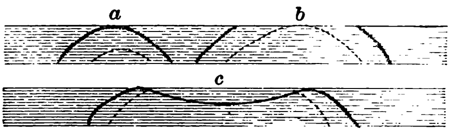


Fig. 136.

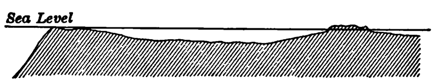


Fig. 137. — Section of actual coral reef.

ing a shallow *lagoon* or lake of water. These ring-shaped islands, or *atolls*, are of all sizes, from one to a hundred miles in length, but the

Fig. 138. — An atoll.

area above water is very small, often consisting of a few islets rising here and there from the submerged reef.

Fig. 139. — Map of an atoll.

A volcanic island often has a *fringing reef* of coral along its shore. In other cases it is surrounded by a *barrier reef* some distance out from the shore, where the food supply and the absence of mud favor a vigorous growth of coral. The waves are continually breaking up the reef and grinding it into calcareous sand and mud, which fill the spaces between the coral branches. The whole mass rapidly becomes cemented into solid limestone rock which shows little or no indication of its origin. Thus the tops or slopes of the volcanic peaks become crusted over with limestone known in one case to be at least 1000 feet thick.

Fig. 140. — Part of a coral reef. (Great Barrier Reef, Australia.)
(From a photograph loaned by the American Museum of Natural History, New York.)

Coral reefs and islands are most numerous in the western Pacific Ocean. They also occur in the northern part of the Indian Ocean and in the western Atlantic. All the extensive coral formations lie in the track of the great equatorial currents (see p. 265), which bring to the growing polyps abundance of warm water and food. They are accumulations of lime which has been extracted from solution in sea water, solidified, and deposited by living plants and animals. Their place in the economy of nature corresponds to that of the salt beds and alkali plains on land.

Results of Sedimentation. — By these various processes of sedimentation the material washed away from the land is finally deposited on the bottom of the sea, being assorted and laid down in layers which are level or only slightly inclined. Each layer of mud or sand is somewhat irregular in thickness and limited in extent, gradually thinning out to an edge where it overlaps and is overlapped by other layers. By pressure and the cementing action of sea water, probably assisted in the deeply buried layers by the internal heat of the earth, the beds of mud and sand near the shore are gradually consolidated into strata of shale and sandstone, while farther from shore, beyond the reach of the coarser sediment from the land, limestones are formed by the rain of shells upon the bottom. Thus mantle rock is reconverted into bed rock, the forms destroyed upon land are reconstructed in the sea, and over thousands of square miles the thickness of the earth-crust is increased by the addition of *sedimentary rocks in horizontal strata.*

Realistic Exercise. — The student should return to the study of the streams in his vicinity in the light of Chapters XII and XIII. Nearly all forms of slopes, valleys, divides, cones, fans, alluvial plains, terraces, and deltas may be found; or they may be made at will by the use of a mound of earth and a sprinkling pot.

CHAPTER XIV

MOUNTAINS

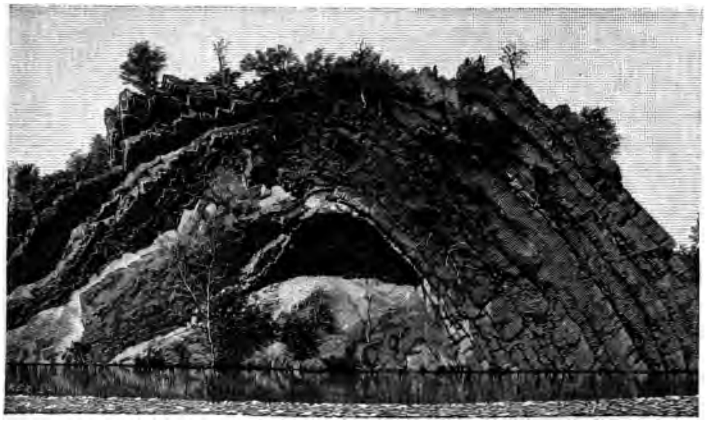


Fig. 141. — Folded strata, Maryland.

Faulted and Folded Strata. — As shown in the last chapter, sedimentary rocks are always laid down in nearly horizontal strata. The greater part of the land surface is found to be made up of (or underlain by) similar strata which must have been formed originally under similar conditions, and subsequently upheaved to their present elevation (see Figs. 14, 15, 18). Over large areas of plains and plateaus the strata have been lifted bodily upward with little or no displacement of parts or disturbance of their original smooth horizontality. In other regions they have been tilted, folded, and broken into every degree of confusion.

A *fault* is a fracture accompanied by displacement of the strata. It may be accompanied by a bending up or down of the strata. The

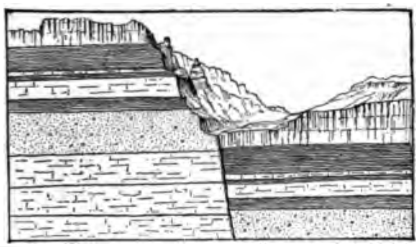


Fig. 142. – A fault.

amount of *throw* or vertical displacement is sometimes as much as 20,000 feet.

A *syncline* is a downfolding of the strata in the form of a trough, as at *a*, Fig. 143.

An *anticline* is an upfolding of the strata in the form of an arch, as at *b*, Fig. 143. An anticline is sometimes overthrust, as in Figs. 144 and 145.

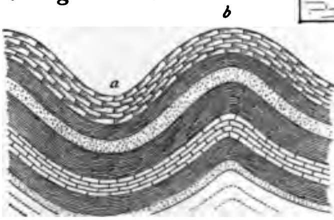


Fig. 143

Compressed folds are a series of sharply bent synclines and anticlines in which the connecting limbs are parallel and nearly vertical, as shown in Fig. 146.

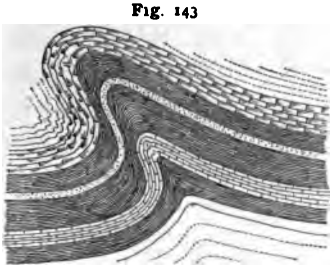


Fig. 144.

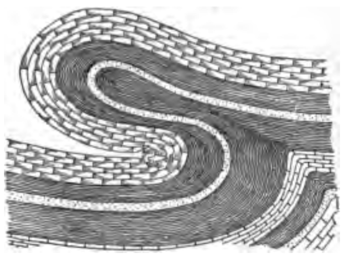


Fig. 145.

A *fan fold* is an anticline which has been pinched at the bottom until it is narrower there than at the top, as shown in Fig. 147.

In nature these forms are seldom found complete, but more or less extensively eroded.

Fig. 146.

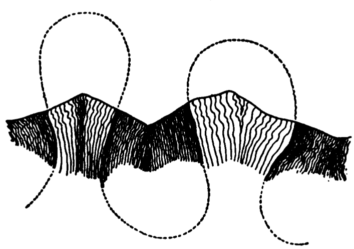


Fig. 147.

Mountains. — Any relatively great elevations of land having steep slopes and a sharp or narrow top are popularly regarded as mountains. The term includes features which vary widely in form, dimensions, structure, and origin. A single mountain rarely exists by itself except in the case of volcanic cones (see Chapter XV). A mountain *range* is a long ridge having two principal slopes and a crest, which may be jagged or level like the ridge-pole of a barn. It may be straight and simple, or, as is more commonly the case, it may be curved or irregular and send out many branching spurs.

Fig. 148. — An irregular mountain range.
(Park Range, Colo.)

The important part of the range is not the peaks, which may attract attention, but the broad continuous mass which supports them (Fig. 149). Usually but a small portion of a range can be seen at once or

Fig. 149. — Teton Range, Wyoming.

shown in a picture ; hence erroneous ideas are apt to be acquired concerning their steepness, ruggedness, and confusion.

Ranges are often found combined in chains, and chains in systems. Mountains are usually portions of the earth-crust which have been not only uplifted but also deformed and dislocated. The special character of the mountains is primarily determined by the nature of the deformation.

Block Mountains. — Probably the simplest mountains in existence are those of southern Oregon and northern California and Nevada. This region is traversed by numerous ridges which extend north and south and are separated by barren valleys and playa lakes. They are from 10 to

Fig. 150. — Section of block mountains.

100 miles long, 3 to 20 miles wide, and 1000 to 5000 feet high. They have a steep slope on one side, often rising in a sheer precipice to a height of 2000 feet or more, and may be easily recognized as broken blocks of the earth-crust which have been tilted, some one way and some another. They resemble the roofs of old-fashioned houses with unequal slopes. The long back slopes *B*, Fig. 151, are formed by the surfaces of the strata, while the steep slopes *E* are formed by their broken edges. *T* is a trough block, forming a "rift valley" by its subsidence.

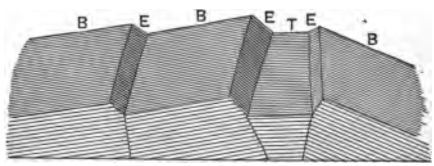


Fig. 151.

Many of the mountain ranges of the Great Basin are of similar structure; but most of them are much more complicated. The younger

Fig. 152. — Half-buried mountains, Utah.

ranges still retain their straight crests and even slopes. The older ranges have been carved by prolonged erosion into extremely rugged forms. The crests are jagged, the slopes are ridged by spurs and valleys, and the original form has been changed until it is hardly recognizable. The valleys between are broad plains of sand and gravel washed from the mountains. On account of the scanty rainfall there are few permanent streams to carry away the débris, which has accumulated until the ranges are half buried in their own waste.

Simply Folded Mountains. — The Uinta Mountains in northeastern Utah extend east and west about 120 miles. The width of the range is forty miles. The crest follows an irregular line north of the center, is cut by a few shallow notches or passes, and rises at some points to a mile and a quarter above the surrounding plateau. The slopes are broken by parallel spurs, which branch out from the crest and are separated by transverse valleys. The range has been formed out of a single broad arch or flat anticlinal fold, which has been greatly eroded.

The structure is slightly complicated by the occurrence of a fault along the north side. From the dip of the strata upon each side, the original height of the arch above the present crest has been calculated, and it appears that a thickness of three and one half miles of rock has been removed. This does not imply that the mountains were ever

three and one half miles higher than at present: for erosion has gone on at the same time with upheaval. Figure 153 shows in the foreground

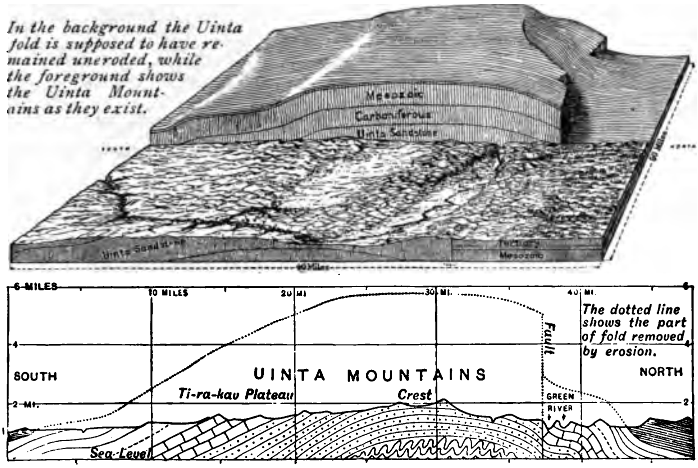


Fig. 153.

the mountains as they are, and in the background the mountains as they would be if the eroded material were restored.

The Jura Mountains in France and Switzerland consist of a series of parallel ridges and valleys in which each ridge is an anticline and each valley is a syncline. They are so young that only the topmost layers have been eroded from the arches, and the floors of the troughs have been thinly covered with mantle rock.

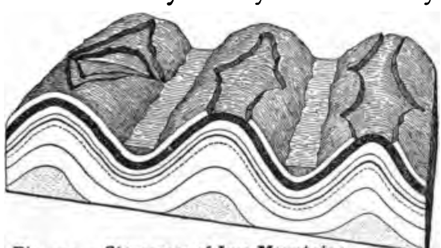


Fig. 154. — Sterogram of Jura Mountains.

Complexly Folded Mountains. — Few mountain systems are as simple as those just described. In most cases they owe their existence primarily to extensive foldings and

faulting which combine to give them a very complex structure. Figure 155 shows the variety of structure which exists in the Appalachian highland, and the extent to which erosion has modified the original forms in that region. The forms produced by the process of upheaval have been almost entirely destroyed, and the present mountains are quite different from the original Appalachians. Strata having a thickness of at least five miles have been removed from the highland, and scarcely more than the stumps of the old mountains now remain.

Fig. 155. — Section of Appalachian Mountains.

At 1, Fig. 155, a series of compressed folds has been worn down to a plain, the surface of which is formed by the edges of the nearly vertical strata. At 2 an anticline has been reduced to a valley, and at 3 a syncline is left standing as a ridge made up of concave strata like a pile of platters. The ridges at 4 are projections of hard strata above the more easily eroded ones on either side. Most of the present ridges are of this character, and their parallel zigzags are shown in Fig. 156. With level crests rising to a nearly uniform height, they stretch across the country like gigantic walls. Adjacent ridges frequently approach each other and unite at a sharp angle, inclosing a valley, the structure of which is shown in Figs. 157, 158. In Fig. 157 the bed of hard sandstone which forms the ridges is continuous under the valley, and its shape resembles the prow and bottom of a canoe. The region occupied by the Appalachian valleys and ridges is about seventy-five miles wide, and extends through Pennsylvania, Maryland, and Virginia into Tennessee. It is bounded on the east by a much older mountain range, the Blue Ridge (*B*, Fig. 155), and on the west by the eastern escarpment of the Alleghany plateau (*A*, known as the Alleghany Mountains), in which the strata have been but slightly disturbed.

The drainage of the Appalachian highland presents many interesting peculiarities. The principal

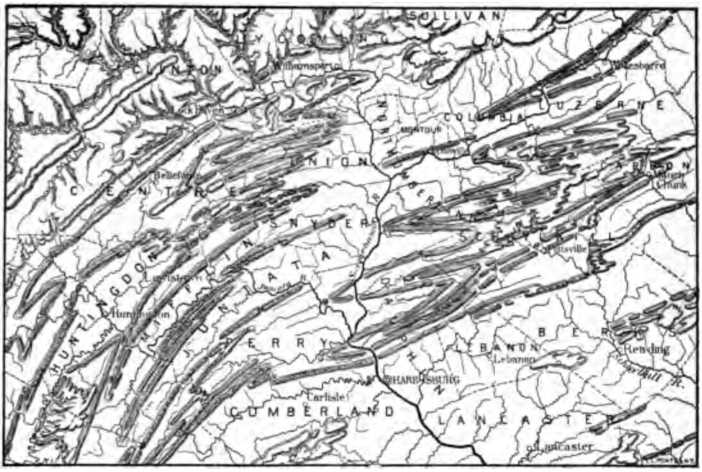


Fig. 156. — Part of the Appalachian Mountains, in Pennsylvania.

rivers, the Delaware, Susquehanna, and Potomac, rise in the western plateau and flow southeastward directly across the trend of the ridges, through which they pass by means of water gaps. The tributary streams follow the valleys between the ridges, and with their branches present systems of trellised drainage (see p. 160) in great perfection. The main streams are independent of the relief, and flow across the trend of the ridges rather than parallel with it.

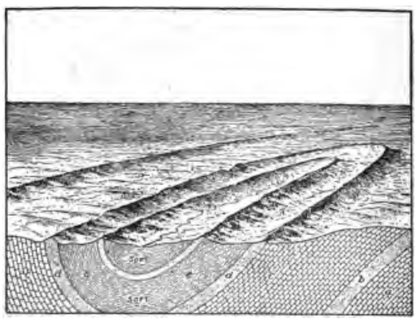


Fig 157. — Eroded syncline; canoe valley.

Such relations between relief and drainage must be the result of a long period of adjustment. The level sandstone-topped ridges of uniform height and the softer strata of shale and limestone in the valleys

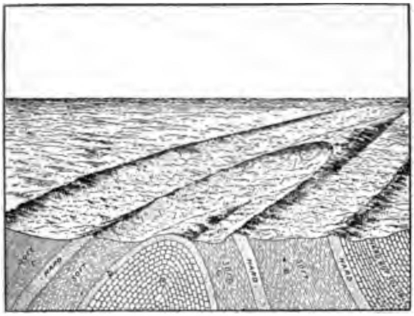


Fig. 158. – **Eroded anticline.**

between suggest the explanation. The original Appalachian folds were in past ages worn down to a nearly level plain sloping gently to the southeast, across which the large rivers followed the same courses as at present. The plain was then uplifted to the height of the present ridge crests, and as the revived streams cut their valleys into it, they came down upon the alternations of hard and soft rocks. While the main streams were slowly sawing their gaps into the sandstone, the tributaries were

Fig. 159. – **The Delaware water gap.**

able to erode wide valleys out of the limestones and shales (see Figs. 157, 158, and 160). By a series of adjustments as explained on page 159, all the smaller streams in each valley combined into one system tributary to a master stream which was able to cut its gap down more rapidly than the rest. Thus the trunk streams became superimposed

upon the new surface and their tributaries maturely adjusted to its structure. Every ridge and valley in the present Appalachian Mountains is the product of erosion, but the arrangement of hard and soft strata is due to the original upheaval and folding. The internal forces of the earth furnished a block of peculiar structure, from which air, rain, frost, and running water have carved out the present peculiar and elaborate pattern of relief.

Fig. 160. — Water gaps of the Susquehanna.

In many lofty mountain ranges the strata have been doubled up, crushed, contorted, overturned, and shoved upon one another in wild confusion.

Figure 161 shows a portion of the typical structure of the Alps. The central core of such ranges usually consists of granite or some allied igneous rock, from which the layers of sedimentary rock which once covered it have been removed. The unstratified granite and the edges of the highly inclined strata have been split by frost into a thousand sharp and jagged ridges, peaks, needles, and "horns." Although the peaks, ridges, passes, and valleys are conspicuous and occupy the whole landscape, they are superficial features, and form but a small part of the great mass of the range which supports them (compare Fig. 162 with Fig. 149).

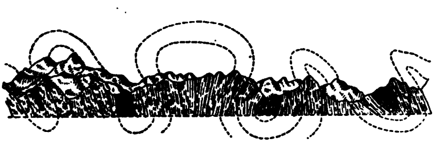


Fig. 161.

Fig. 162. — Alpine scenery.

Relict Mountains. — In many cases mountains of complex structure have been worn down to their roots, and their surface forms bear apparently little relation to the arrangement of the material in their mass. But the peaks and ridges mark the place of harder and more resisting rocks which have been left prominent by the removal of less resisting rocks around them. The mountains of

Used by courtesy Boston & Maine Railroad.

Fig. 163. — Mount Monadnock, in southern New Hampshire.

southern New England (see Fig. 163) and the Scotch Highlands are examples of this class, which may be called *relict* mountains. Their rounded smoothness of outline is due to glacial abrasion.

Plateau Mountains. — Some massive elevations which have the appearance of mountains and are popularly so called hardly deserve the name. They are really dissected

Fig 164. — Dissected plateau.
(Scott County, Tenn.)

plateaus. The strata have been but slightly if at all dislocated by faulting or folding, but are deeply cut by stream valleys. The interstream ridges are mountainous in size, but the strata of which they are composed remain nearly horizontal, and may be traced from one ridge to another across the valleys. The Catskill Mountains in New York, and the Alleghany plateaus of Pennsylvania and West Virginia, are plateau mountains.

Summary. — The general term *mountains* includes a variety of land forms which differ in their structure and origin. They have the common characteristics of large mass, elongated outline, and great elevation. They are the products of two sets of forces, one of which acts within or below the earth-crust to produce elevation, and the other acts on the surface of the crust to produce degradation. In mountains like the Oregon blocks and the Jura the internal forces are supreme and almost wholly responsible for the form. In mountains like the Appalachians internal forces have folded and dislocated the strata, but the present forms are almost wholly due to erosion. Every degree of gradation between these extremes may be found. In every range internal forces have raised the massive block out of which external forces have carved the details of ridge, spur, peak, pass, and valley. It follows that lofty mountains, like the Himalayas, Alps, Rocky, and Sierra Nevada, are lofty because they are young; and that low, subdued mountains of complex structure, like the Appalachians and the Scotch Highlands, are low and subdued in outline because they are old.

Earthquakes. — The elevation, depression, folding, and faulting of the earth-crust show that it is subject to a variety of stresses and strains. When it finally yields to an increasing stress and a displacement suddenly occurs, a violent jar results, which is propagated through the crust, like that which is painfully felt when a stick bent in the hands suddenly breaks. The speed with which the shock travels is about three miles per second, and it often extends completely through or around the earth. The *focus* or place where the break or slip occurs may be at a depth of several miles, but the jar travels upward and outward in ever-widening circles, diminishing in violence

as it proceeds. The surface movements thus produced constitute an *earthquake*, which is most violent at a point directly above the focus. The actual distance through which any given point of the earth's surface is moved seldom exceeds a small fraction of an inch, but the velocity of the motion may be so great as to make the jar exceedingly destructive. Great cracks open in the earth, and from them mud and hot water are sometimes expelled. Landslides are started, and streams are dammed or turned out of their courses. Buildings are cracked or thrown down, and cities destroyed with great loss of human life. Some of the most destructive effects are produced by earthquakes under the sea, which disturb the water so violently that great waves rise over the shores and sweep everything before them.

Fig. 165. — Earthquake crack, Arizona.

Earthquakes occur chiefly in regions which are still undergoing movements of elevation and folding, and hence are intimately associated with young mountains and volcanoes. They are especially frequent along the borders of the Pacific Ocean, where the slopes of the continental plateau are steepest. In Japan noticeable shocks occur almost daily, and delicate instruments show that the earth-crust is in a continual tremor.

Causes of Folding and Faulting. — The phenomena of folding and faulting evidently depend upon deep-seated conditions and forces in the interior of the earth. The thick beds of sedimentary rock which compose the mass

of great mountain systems or rise high upon their flanks were certainly laid down in a nearly horizontal position upon the bottom of the sea. They have been not only elevated to their present position, but in the process of elevation have been extensively fractured, contorted, folded, and crushed in a manner which indicates that they have been subjected to enormous and prolonged lateral or horizontal pressure.

The folded strata which underlie a certain area in Pennsylvania sixteen miles wide would, if smoothed out to a horizontal sheet, extend ninety-six miles. The folding which has occurred in the Appalachian region has reduced its original breadth about eighty-eight miles.

Folded structure like that of Fig. 154 can be most easily imitated by laying a pile of sheets of rather stiff paper upon a table and compressing them lengthwise. Faulting and other important details may be imitated by compressing layers of clay, plaster, or wax by means of a screw.

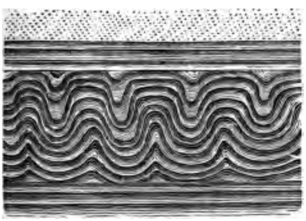


Fig. 166. — Clay compressed lengthwise.

Most of the typical displacements and deformations of strata may be easily and naturally accounted for by supposing that the earth-crust has in some way become too large for the centrosphere. *Readjustment under compression* seems to be the key to most of the problems of mountain structure. Either the crust has grown larger than it was originally or the centrosphere has grown smaller.

The theory that the earth has been for ages a cooling and therefore a contracting globe, and that while the crust on account of exposure to the heat of the sun has

ceased to cool and contract the centrosphere continues to do so, is not free from objections and difficulties; but in the present state of our knowledge it seems to be the most satisfactory explanation yet proposed.

Regions like the Great Basin, which are traversed by faults, form exceptions to the rule that the earth-crust is under compression. As shown in Fig. 151, each fault block is wedge-shaped and those with a broad base have gone up while those with a narrow base have gone down. This is equivalent to the insertion of a series of wedges into the crust so as to enlarge it. The tilted blocks of the Great Basin act as if they were floating upon a liquid layer below, like blocks of ice upon water, which may be the actual case. It seems evident that in this region the earth-crust has been subjected to stretching instead of compression; otherwise the blocks would not have found room to rise or sink between their neighbors. This may be accounted for by supposing that this portion of the crust forms the crown of a broad arch, and in crust folding the crowns of the arches or anticlines are always put upon the stretch.

CHAPTER XV

VOLCANOES

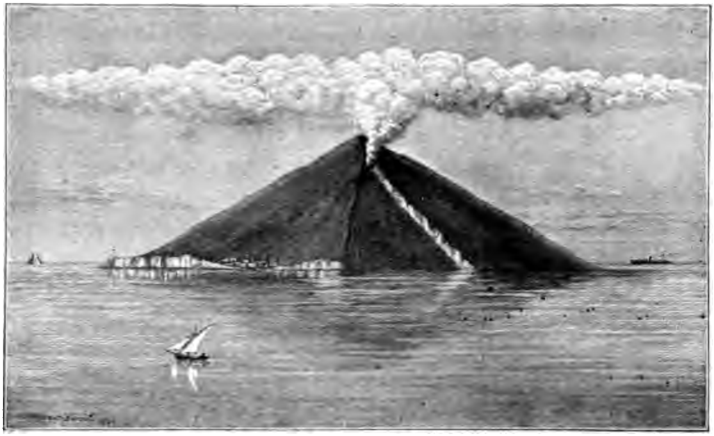


Fig. 167. — Stromboli.

Stromboli. — The island of Stromboli rises from the Mediterranean Sea north of Sicily. It is a conical pile of material resembling cinders or the slag of an iron furnace.

Fig. 168. — Crater of Stromboli.

It is 4 or 5 miles in diameter and 3000 feet high. At a point on the steep slope about 1000 feet below the summit there is a circular hole from which a cloud of steam continually escapes as if from a chimney. If

one climbs to a point which commands a view of the hole from above, the steam is seen to issue from cracks in a black crust which forms the bottom of a bowl-shaped hollow or *crater*. . From some of the cracks steam is blown out in puffs with a loud snorting noise like that made by a locomotive engine. In other cracks a thick semiliquid substance heaves up and down, until finally a great bubble bursts with a rush of steam which carries fragments of the liquid several hundred feet into the air. At night the liquid is seen to be white-hot and the crust glows with a dull red color. Whenever the crust is broken by the bursting of a bubble, an incandescent surface is exposed from which the light flashes up on the steam cloud above, as it does when a locomotive fireman opens his furnace door.

Stromboli is a *volcanic cone* and in its crater may be seen in a mild and simple form the essential features of a volcanic eruption. It will be observed that it is not a "burning mountain"; in fact, there is next to nothing combustible in it. The appearance of flame above the crater is due to the illumination of the steam cloud by the white-hot *lava*, or melted rock, below. The lava in the crater acts very much like a kettle of mush, porridge, or molasses set over a fire. Steam is formed at the bottom, but can not escape readily on account of the thick, viscid character of the substance. The liquid boils and bubbles, gradually rising until it overflows the edge of the kettle or until a sudden and violent outburst of steam throws it in every direction. The island of Stromboli is entirely made up of material which has thus been expelled from the crater and piled up around it. The base of the pile rests upon the sea bottom, where the crater must have at first opened, more than 3000 feet below the surface. The eruptions of Stromboli are sometimes more violent than those just described, but they are always due to the formation of steam in a mass of melted rock and the explosion of the bubbles.

Fig. 169. — Section of Stromboli.

Vesuvius is a conical mountain 4000 feet high, rising from a plain on the shore of the Bay of Naples. The upper part of the cone is half surrounded by a semicircular ridge of nearly equal height called Monte Somma. At the beginning of the Christian era this ridge formed part of the wall of a complete crater about three miles in diameter, the bottom of which was occupied by a forest. In the year 79 this volcano suddenly burst into violent activity. The explosions blew away the south half of the crater rim, and scattered the material over the country, burying the cities of Pompeii and Herculaneum with mud and ashes. Since that time the present cone has been built up inside the rim of the old crater. Vesuvius has long periods of rest, or of mild activity in which it resembles Stromboli.

Fig. 170. – Monte Somma; Vesuvius in the background.

Fig. 171. – Vesuvius and Monte Somma, as seen from Pompeii.

Globular masses of steam escape in rapid puffs and form a spreading cloud above the mountain. At the same time hot stones are hurled into the air, and fall back with a rattling sound like that of coal thrown into a cellar. The escaping gases, like the steam from the nozzle of a boiling tea-

kettle, are at first transparent, but change as they rise into bluish white fleecy clouds, while a peculiar "wash-day" odor is very noticeable. Small streams of liquid lava may be seen flowing down the side of the cone like liquid iron from a furnace. The surface of the lava soon cools and hardens into a stiff scum which becomes wrinkled like the cream on milk which is being poured from the pan.

At irregular intervals the eruptions become much more violent. The explosions occur so rapidly as to make a continuous roar, the whole of the neighboring region is shaken, vast volumes of steam mixed with dust rise three or four times as high as the mountain, the cone is split by fissures from which lava streams flow, and the summit seems to sweat fire. Volcanic *bombs*, or whirling masses of lava, are thrown thousands of feet into the air; the steam condenses into rain which is made dirty by the dust in the air and, mingling with the sand and stones, produces torrents of mud which overwhelm fields and villages. The eruption may continue for several days, but it gradually subsides, leaving the cone and crater changed in form and dimensions.

Fig. 172. – Vesuvius in eruption, April, 1872.

These examples illustrate the essential feature of every volcanic eruption. It is the escape or expulsion of solid, liquid, and gaseous material from the interior of the earth. The hole or fissure from which the material escapes is the *pipe* or *chimney*, the hollow around its top the *crater*, and the heap of materials piled around it the *volcanic cone*, or mountain. Steam forms more than ninety-nine per cent

of all the gases given off. The lava or liquid portion is simply melted rock, while the dust, often called "ashes," sand (*lapilli*), and larger stones or "cinders" are portions of lava blown into spray or clots by the explosion of steam. *Pumice* is a glassy lava which has been puffed up by steam bubbles into a light, spongy substance. Masses of lava having a coarsely cellular structure like bread are called *scoriæ*. Most of the volcanoes of the world resemble Vesuvius in general character, but some are more violent, and others less so.

Krakatoa. — The most violent and destructive volcanic eruption of modern times occurred in 1883 from the island of Krakatoa in the Strait of Sunda. During a series of explosions a mass of rock estimated at one cubic mile was blown into the air in the course of a few hours. A column of steam and dust rose to a height of seventeen miles and spreading out covered the sky with a black cloud which carried the darkness of midnight for scores of miles around. A rain of dust, sand, and fragments of pumice covered the sea and land. The noise of the explosions resembled that of heavy cannonading, and was heard at many places more than 2000 miles distant. The finest dust blown into the upper air was distributed by air currents all around the earth and did not completely subside for two or three years. Air waves were started which traveled three and a half times around the earth. The sea waves rose on the neighboring shores to a height of fifty feet, destroyed the lives of 35,000 persons besides a vast amount of property, and were felt on the shores of America 12,000 miles distant. About one half the island of Krakatoa was blown away, and in the place where a peak half a mile high had stood, the water is now 1000 feet deep.

Hawaiian Volcanoes. — The island of Hawaii is the largest volcanic pile in the world. It is a mass of lava from 70 to 90 miles in diameter, rising from water 15,000 feet deep to a height of 14,000 feet above sea level. There are four principal craters, of which two are now active. The summit of Mauna Loa, one of the highest points of the island, is a flat plain in the midst of which is a pit 3 miles long and nearly 2 miles wide and 1000 feet

deep. This often contains a lake of lava thirty or forty acres in extent. From the surface of the lake columns of lava shoot up like a fountain to the height of several hundred feet. The lava seldom overflows the rim of the crater,

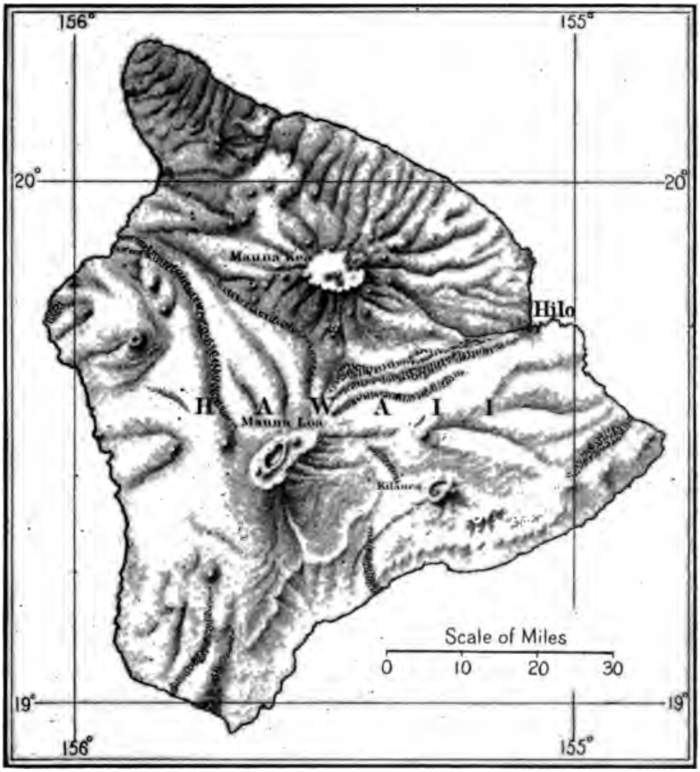


Fig. 173. — Map of Hawaii.

but bursts through the side of the mountain at lower levels, spouting high into the air and forming a river of molten rock. After this the level of the lake in the crater subsides.

On the eastern slope of Mauna Loa and nearly 10,000

feet below its summit is another crater called Kilauea. This pit is from two and a half to three and a half miles in diameter. Near its center is a pool or boiling spring of lava. Part of the time this pool is covered with a black crust showing a rim of fiery liquid around its edge. Jets and fountains shoot up here and there, play for a few minutes, and subside. At intervals the whole crust becomes broken by a network of cracks, each separate piece turns edge downward, and sinks, and the pool is left an unbroken expanse of glowing lava. Then the surface of this lake of rock freezes again. The pool is undoubtedly the top of a column of lava which extends downward thousands of feet. By repeated overflows of such lava pools the vast crater gradually fills nearly to the brim; then, as the lava is drawn off through some subterranean outlet, its floor subsides until the pit is 1000 feet deep.

Fig. 174.— Kilauea; lava lake.

Volcanic vents like Mauna Loa and Kilauea may be thought of as springs or wells of liquid rock, the level of which varies with the supply and the facilities for escape. They are called *calderas*, or caldrons, and are distinguished by their great size, the extreme fluidity of their contents, the absence of violent explosions, and their habit of draining off at lower levels instead of overflowing.

The lava streams which flow down the slopes of Mauna Loa are sometimes half a mile to three miles wide and attain a length of forty-five

miles. When, as occasionally happens, a stream flows into the sea, the water is made to boil, the lava is shivered into fragments by the sudden cooling, and the air is filled with a fine glassy dust. The flow is at first very rapid and broken by cascades like those of a river, but as the gentler slopes are reached at lower levels, the stream spreads out, cools, stiffens, and is checked by its own want of fluidity. In flowing through forests it surrounds the trees, and may kill without destroying them. Islands of living forest are sometimes left in mid-stream. In highly liquid lavas like those of Hawaii a solid crust often forms over the surface while the liquid in the interior drains away, leaving a long, winding

Fig. 175. — Lava Cascade.
(Lava flow of 1881, Hawaii.)

Fig. 176. — Ropy lava, Hawaii.

tunnel or cavern. In other cases the crust breaks up into huge blocks which are carried along like cakes of ice in a river, and when the stream

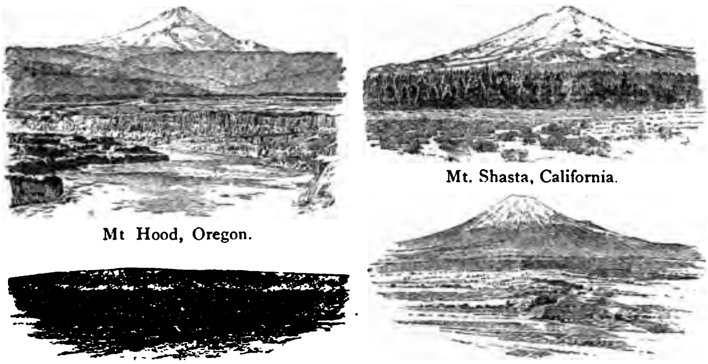


Fig. 177.—Profiles of volcanoes, showing slopes.

finally solidifies are left in confused heaps which are difficult and dangerous to travel over, if not impassable. The surface resembles that of an ice gorge in a river or of the pack ice piled up by the currents in the polar oceans. If the lava stream is thin, the surface does not break up into cakes, but becomes wrinkled, ropy, and diversified with rounded projections, resembling a tangle of cables (Fig. 176).

The slope of a volcanic cone depends upon the nature of the material. If the cone is made

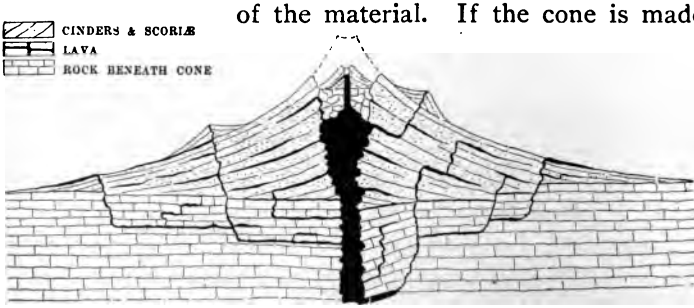


Fig. 178.—Ideal section of a volcano.

up chiefly of coarse cinders and scoriæ, it is very steep. The slope of an ash cone is more gentle, while liquid lava

spreads out easily into a still flatter mound, the extreme being seen in the very liquid lavas of Hawaii, where the slopes are seldom more than seven degrees. Most volcanic mountains are of complex structure, being built up of successive layers of ash, cinders, and lava in roughly stratified arrangement. The strata slope away from the center and are bound together by radiating *dikes*, or nearly vertical sheets of lava which fill cracks made at times of eruption.

Lava Flows. — The Columbia plateau, an area of 200,000 square miles, mostly in Idaho, Washington, and Oregon, is formed by a series of lava sheets which in some places have a thickness of more than 4000 feet. The smooth surface of the lava meets the slopes of older mountains as the surface of the sea joins a rugged coast. It extends up the valleys and indentations and is itself indented by projecting headlands, while some mountains are completely surrounded and form islands in a frozen sea of lava. In some places it has been extensively eroded by streams, and in others broken by faulting into blocks, as in the block mountains of Oregon.

Fig. 179. — Map of Columbia lava flow.

Through the plateau the Snake River has cut a canyon which rivals in dimensions the Grand Canyon of the Colorado. From the exposed sections it appears that the hills, valleys, and mountains of the original surface were buried and obliterated by the lava flow, much as those of eastern North America were buried by the ice sheet. Buried soils, forests, and lake sediments, interbedded between the lava sheets, show that the outflow did not take place all at once, but at successive periods

Fig. 180. — Dikes.
(In southern Colorado; the mountain in the background is West Spanish Peak.)

separated by considerable intervals of time. The sedimentary rocks beneath the lava are traversed by numerous dikes which connect with the surface sheets, and indicate that the whole mass of the lava cap probably flowed out quietly from fissures in the earth-crust, and spread over the face of the country.

A much older lava sheet of equal extent forms the plateau of Dekkan, in India.

Dikes, Sills, Laccolites, Plugs, and Necks.— Cinder cones, beds of sedimentary rock, and other formations are often found to be traversed by nearly vertical sheets of hardened lava which clearly form no part of the original structure. The lava has been injected from below while in a liquid state, and has cooled without exposure to the air into a compact mass which shows no sign of having been permeated by steam. Such masses are called *dikes*.

Fig. 181. — Chasm formed by erosion of a dike.
(Cape Ann, Mass.)

When the dike material is harder than the rock into which it was intruded, it is, by the process of erosion,

left standing above the surrounding surface like a wall (Fig. 180). Where the dike penetrates harder rocks along the seashore, it is eroded by the waves more rapidly than the surrounding rock, and thus gives rise to "chasms" (Fig. 181), "purgatories," and spouting caves.

Lava has been forced not only into vertical cracks, but also between the layers of stratified rock, where it has hardened and forms more or less horizontal *sills*. In some instances the quantity of liquid rock forced into one locality is sufficient to raise the overlying strata into a dome which appears upon the surface as a mountain. Such accumulations of igneous material in the midst of sedimentary rocks are called *laccolites* (*stone cisterns*). Subsequently they may be exposed by the erosion and removal of the overlying strata, as is the case in the Henry Mountains of Utah. The laccolite of Mt. Hillers in this group is three miles in diameter and 4000 feet deep (Fig. 183).

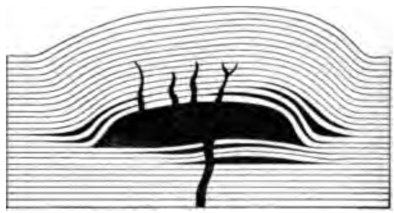


Fig. 182. — Ideal cross section of a laccolite.

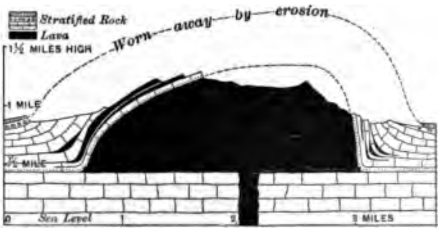


Fig. 183. — Cross section of Mt. Hillers.

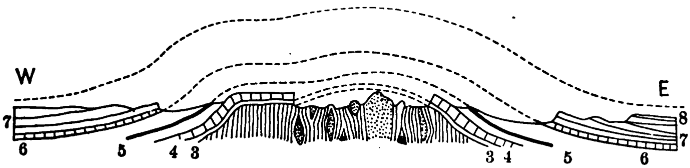


Fig. 184. — Cross section of Black Hills.

The Black Hills of South Dakota are the eroded remains of a dome which if complete would be from 80 to 160 miles in diameter, and 7000

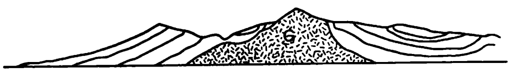


Fig. 185. — **Cross section of Elk Mountains, Colorado.** (G, granite.)

feet high. The central core is of granite, from which the strata of sandstone, shale, and lime-

Fig. 186. — **Cross section of Park Range, Colorado.** (B, lava; M'G, granite.)

Fig. 187. — **Hogbacks** (after Powell). (Northern slope of Uinta Mountains.)

stone dip away in every direction. The edges of the hard strata form ridges which encircle the core, and between them the softer strata have been eroded into valleys which are continuous around the Hills. The Elk, Park, and other ranges of the Rocky Mountains in Colorado seem to be the result of similar upthrusts of strata by an intruded core of granite (Figs. 185, 186). The flanking ridges of hard strata are called "hogbacks" (Fig. 187).

In a few instances the lava has been upthrust in the form of a vertical column which is afterwards exposed by erosion and is known as a volcanic *plug*. Mato-tepee in Wyoming is a plug 600 feet high (Fig. 188). In the last stages of the destruction of a volcanic cone by erosion, the core of hardened lava which filled the original pipe or chimney at its center is

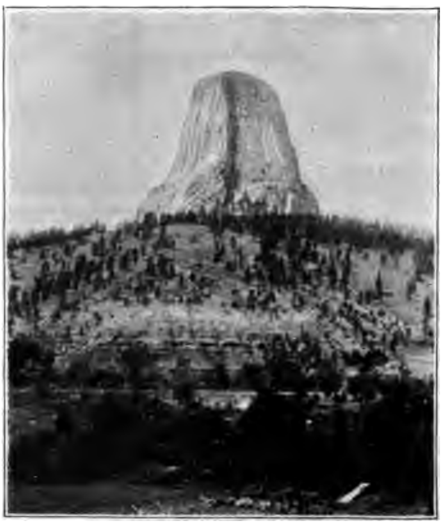


Fig. 188. — **Mato-tepee, Wyoming, a plug.**

left standing alone after the removal of the other material, and forms a lofty butte which resembles a plug but is called a *neck* (Fig. 189).

Fig. 189. — A neck.
(Near Mt. Taylor, N.M.)

Dust Deposits. — The quantity of so-called "ashes" or dust emitted by volcanoes is sometimes so great as to form beds comparable in extent and importance to the lava sheets. Whymper saw a column of inky black dust rise from the crater of Cotopaxi, Ecuador, straight up to a height of 20,000 feet in less than one minute, and then spread out with the wind. The column continued to rise for more than an hour, and the dust was distributed over hundreds of square miles. The quantity which fell was estimated to be not less than two million tons. The fall of sand from an eruption of Conseguina, Nicaragua, in 1835 spread over an area 1500 miles in diameter, and continued for forty-three hours. Near the volcano the country was buried to a depth of several feet, and the deposit was several inches deep 100 miles away. Extensive deposits of volcanic dust, the result of eruptions which occurred in long past ages, extend over large areas in Nevada, Utah, Montana, South Dakota, Nebraska, Oregon, and Washington, attaining in many places a thickness of 30 to 50 feet. Along the Yukon River, a bed of white volcanic dust covers an area of 50,000 square miles, varying in thickness from a few inches to 100 feet.

Distribution of Volcanoes. — Eruptions of material from the interior of the earth have occurred at some period in almost every part of the world, but as Fig. 190 shows, recent volcanic activity is almost confined to regions of young and growing mountains, and is especially marked along the high margins of the continents which border the Pacific and Indian oceans, and among the peninsulas and islands in tropical and equatorial regions.

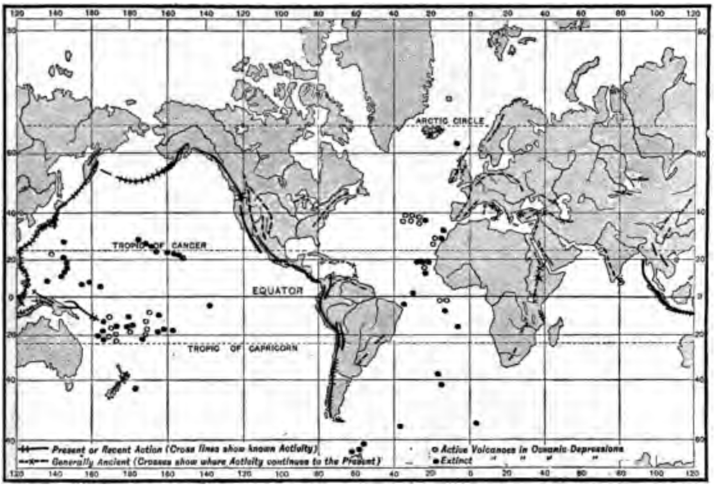


Fig. 190.—**Map showing distribution of volcanoes.**

Causes of Volcanoes.—The most impressive and terrifying displays connected with volcanic eruptions are plainly due to the explosion of steam within the crater; but this does not account for the origin or existence of the liquid rock, nor for eruptions which are not explosive, like those of Hawaii and the lava flows of the Columbia plateau and the Dekkan. It is necessary also to account for the steam itself.

The fact that volcanic eruptions generally occur in regions where elevation and folding have recently taken place or are still going on, indicates that both upheaval and volcanism may be due to the same general cause.

If the rock at a depth of twenty or thirty miles below the surface of the earth-crust (see p. 28) is hot enough to melt, but is kept solid only by pressure, it seems probable that a comparatively slight relief from pressure would be followed by immediate liquefaction. The upfolding of

the strata above, or the occurrence of a fissure extending downward from the surface, would give the rock below more room; the pressure at that point would diminish, and, driven by the greater pressure all around, the now melted rock would rise. The water which the rock originally contained, or which it might meet on its way upward, would expand into steam, and still further assist the rise of the lava column, as the steam formed in a kettle of boiling mush or molasses causes it to rise and overflow. If the lava is thick and viscid, the steam escapes with explosive violence; if it is thin and liquid, the steam passes off more quietly.

CHAPTER XVI

LAND SCULPTURE

THE forces at work within the earth have roughly shaped the large features of its face, — the ocean basins with their level floors, rounded deeps, broad rises, and curving lines of elevation, the continents with their plains, plateaus, mountain systems, closed basins, volcanic cones, and lava beds. One fourth of the face has been exposed to the action of outside agents which have covered these huge and unshapen forms all over with elaborate carving and given them an endless variety of detail. Air, frost, gravity, and running water are great artists, who sculpture in stone their characteristic patterns of ornamental design. Each pattern is the result of a different combination of agents at work upon different materials. The whole assemblage of designs forms the foundation of scenery or the diversified *landscapes* of the earth.

The character of sculptured forms depends upon (1) the *agents*, such as rainfall, temperature, and winds, which vary with the climate; and gravity, which is everywhere practically uniform in force, but not everywhere equally efficient. The work which gravity can do, either directly or through running water, varies with the steepness of the slope. On level plains it accomplishes hardly anything; on sharply inclined mountain sides and perpendicular cliffs its efficiency is very great.

The character of sculptured forms also depends upon (2) the *materials*, which may be soft or hard, brittle or tough, porous or compact, homogeneous or varied in texture, coarse-grained or fine, soluble or insoluble; and upon (3) the *structure*, or arrangement of materials, whether stratified or unstratified, whether the strata are horizontal, inclined, or folded, and whether the hard or soft strata are uppermost. If there were anywhere on the face of the earth a region upon which

no rain ever falls, over which no wind ever blows, subject to no changes of temperature, and so level that gravity is powerless, it would undergo no change from age to age, and would be truly *dead*. No known region even approaches such a condition.

Sculptured Forms in Horizontal and gently Inclined Strata. — The plain south of the Great Lakes presents one of the simplest of sculptured designs. Over a large part

Fig. 191. — Shallow valley in a drift plain

of it the slopes are scarcely perceptible, the material is imperfectly stratified, varies but little in hardness, and is not affected by changes of temperature. The rain soaks into it readily and the run-off is sluggish. In the course of time the streams cut broad trenches a little way into it and develop meanders and flood plains out of all proportion to the volume of water in the channel. Except for these shallow stream valleys and the low bluffs which border them, the landscape is featureless (see Figs. 97, 191).

Similar conditions prevail upon coastal plains recently elevated above the sea, and in filled valleys and lake basins.

A smaller rainfall and greater elevation produce out of quite similar material the elaborate and complex forms of the "Bad Lands" of South Dakota and Nebraska. There a lake basin has been filled with nearly homogeneous, compact clay, occasionally varied by thin beds of sandstone and slightly harder clay. This originally smooth plain has been uplifted, and during the progress of the uplift the neighboring rivers and their growing branches have cut their valleys deeply into the surface, until it has been sculptured into narrow ridges, steep-sided buttes, sharp cones, isolated towers, pinnacles, and castellated forms in endless variety. Some small areas of the original surface remain as flat-topped mesas (see p. 214), which are bounded by high, rugged walls, notched by canyons, and buttressed by projecting spurs.

Fig. 192. — The Bad Lands.
(Washington County, S.D.)

Fig. 193. — The Bad Lands.
(Sioux County, Neb.)

Many of the pinnacles owe their form to a sandstone cap which protects the underlying clay (Fig. 194). The mesas are covered with sparse grass, but the slopes are bare and brilliantly colored. The rainfall is so small that convex slopes are rare and short, the descent from the level summit being abrupt and steepest at the top (see p. 156). A group of such forms bears a strong resemblance to a gigantic city in ruins.

Fig. 194. — A capped tower.
(Vulcan's Anvil, Monument Park, Colo.)

The Colorado plateau region described in Chapter VI presents forms similar to those of the Bad Lands on a much larger scale. The rocks are, for the most part, horizontally stratified, and present considerable variations of texture and hardness. The activity of the streams consequent upon the great elevation of the country has carved out characteristic flat-topped forms of mountainous size. Where the strata are thick-bedded, compact, and of uniform hardness, vertical cliffs a thousand feet high occur. Where the strata are thinner and variable in hardness, there is an alternation of vertical steps and more or less gentle slopes. Extensive outflows of lava have covered portions of the plateau with a protective cap.

Fig. 195. — Lava-capped mesa.
(Raton Mesa, Colo.)

Where the underlying rocks have been undermined by the lateral corrasion of the streams, an isolated block with vertical sides and a flat, sometimes overhanging, top of lava is left standing. These form typical *mesas* (Spanish for "tables").

In the northern part of the Colorado plateau region the strata are gently inclined to the northward, and form a series of tilted steps each of which slopes down to an escarpment or line of cliffs (Fig. 196). The drainage is down the slope and along the foot of the cliffs to the trunk stream which cuts through the plateau (see p. 84). The escarpment is gradually undermined, and made to retreat down the slope. At the same time it is notched by canyons, which often meet at their heads and surround a portion of the cliff cut off from the rest. Such isolated outliers form typical *buttes*, which stand in front of the cliffs like a line of sentinels, and present every degree of separation from the main mass of which they were once a part (Fig. 197).

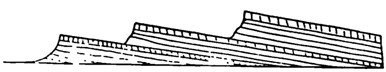


Fig. 196.

Fig. 197. Pink Cliffs and outlying buttes, southern Utah.

Fig. 198. Land of Standing Rocks, near Cataract Canyon, Utah.

Outlying fragments of a former terrane[1] often occur many miles from the nearest cliff or outcrop of similar strata, and furnish a means of determining the amount of *denudation* or removal of strata which has occurred. In Fig. 199 the butte *B* and the mesa *M* are composed of the same strata in the same order as the escarpment *E*, and it is evident that the strata once extended across and filled the intervening spaces. By such evidence it is shown that the average thickness of strata removed from an area of 15,000 square miles on the Colorado plateau can not be less than 10,000 feet.

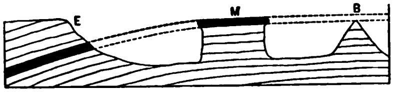


Fig. 199.

Fig. 200. — A young plain.
(Red River basin, N.D. and Minn.)

Fig. 201. — A dissected plateau.
(Tioga and Potter counties, Pa.)

Development of Sculptured Forms. — The sculpture of a plateau of horizontal or gently inclined strata presents

[1] Any mass or series of rocks of large extent is called a terrane.

several recognizable stages of progress. (1) Its originally smooth surface is the result of its structure and conforms to the surface of the upper stratum. The region is *young* and the landscape is featureless (Fig. 200). (2) The streams cut deep trenches into it and their tributaries extend their head waters in every direction. The plateau is cut by a network of water channels into a group

Fig. 202. — A peneplain, northern Virginia.

of ridges and blocks of very irregular size and shape. The tops of most of them are flat and their sides steep, while the valleys are narrow and V-shaped. (3) As the streams widen their valleys the ridges grow narrower until they are sharp-crested, and the blocks grow smaller until they become conical, pyramidal, or dome-shaped. The ascent out of one valley to a divide is immediately followed by a descent into another. The originally smooth surface has been changed into a surface of the utmost possible roughness and the plateau is said to be *maturely dissected* (Fig. 201).

(4) As erosion continues, the ridges and hills grow smaller, lower, and more rounded, until all abrupt and prominent irregularities disappear, and the once elevated plain, reduced to a gently undulating, low-lying *peneplain*[1] (Fig. 202), returns in its old age to the nearly featureless condition of its youth.

Sculptured Forms in Folded Strata.—Any system of rock folds, however complex, consists essentially of a series of arches and troughs (anticlines and synclines). In the process of folding, the anticlines have been subjected to a stretching force and are more or less broken at the crown of the arch. They are also elevated into regions where frost and changes of temperature are more efficient; hence anticlines are especially subject to rapid weathering and disintegration. The mantle rock is easily removed down their slopes, and, accumulating in the structural valleys, partly protects the synclines from erosion (see Fig. 154). The harder and softer strata of the anticline are affected unequally, and the form resulting from the process of sculpture is usually a plateau traversed by parallel ridges and valleys (Fig. 203). But with prolonged erosion anticlines are reduced to valleys and synclines remain as ridges (Fig. 204). These occur frequently in the Appalachian highland (see Fig. 155).

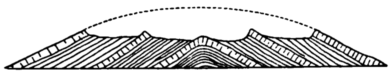


Fig. 203. — Eroded anticline.

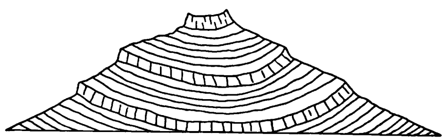


Fig. 204. — Eroded syncline.

The forms which result from the sculpture of highly folded, contorted, and overthrust rocks are so complex and

[1] *Pene*, almost, and *plain*.

confused as to defy classification. Some examples are given in Figs. 162, 205, 206. They present irregular groups and series of jagged crests and sharp peaks separated by

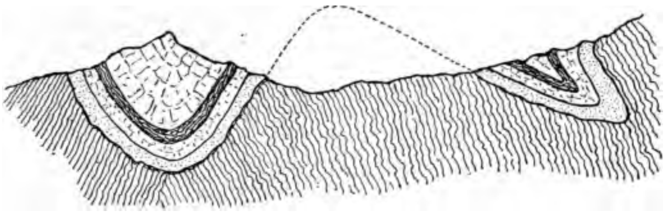


Fig. 205. — Alpine sculpture.

narrow and profound valleys, the surface of which does not correspond to the form of the folds.

In every mountain system the valleys may be distinguished as in part *structural*, or due to the original folding, and in part *sculptured*, or due to erosion. The structural valleys are *longitudinal*, extending lengthwise between the ranges, and have usually been greatly modified by erosion. Every stream which flows down the slope of a mountain range cuts a *transverse* valley, which frequently extends from crest to foot. The ridges between the transverse valleys form spurs extending at right angles to the main crest (see Fig. 148). When two streams on opposite sides of a range have their head waters near together, in the course of time the divide is eaten away until there is cut in the crest line a notch which may extend downward to one fourth or one third the height of the range. These notches are called *passes*, and afford the easiest routes of travel across the range. Thus the crest may become divided into a series of passes and peaks.

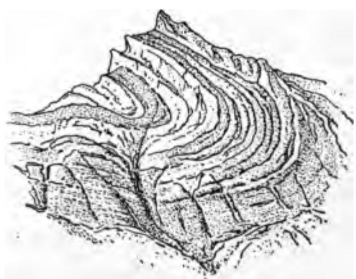


Fig. 206. — Alpine sculpture.

Mountain ranges, like plateaus, are subject to denudation and final destruction by the agents of erosion. The Height of Land between the Great Lakes and Hudson Bay was once a mountain range which may have been as lofty as the Alps, but

has been broken and ground down by weathering and glacial abrasion until it is a broad, plateaulike ridge conspicuous only by its influence upon the direction of drainage. The plateau of southern New England consists of the stumps of old mountain ranges which have been reduced to a peneplain and reëlevated. Only the folded and disturbed position of the rocks and an occasional projecting knob of hard material, like Monadnock and Wachusett, remain to indicate that mountain ranges once existed there.

Glacial Sculpture. — The effect of glacial action upon the form of the land has been considered in Chapter X. The general tendency of glacial abrasion is to rub down

Fig. 207. — Glaciated profile. (Carey Island.) **Fig. 208. — Unglaciated profile.** (Dalrymple Island.)

(Two islands of like geological structure, near Greenland.)

projections and angles, to gouge out soft rocks, and to produce a surface of rounded knobs and hollows. The contrast between a glaciated and an unglaciated surface is often very sharp and conspicuous.

Mountains in high latitudes are generally less jagged and have more smoothly flowing outlines than those in temperate and tropical regions. The passage of a glacier through a stream valley changes its form from V-shaped to U-shaped. Whether glaciers exert a scooping action and excavate valleys to a greater depth in one place than another, thus forming rock basins, like those of the Finger Lakes (pp. 140–142), is a question which has been earnestly discussed. The evidence seems now conclusive that they have done so. Many valleys in the Alps, Himalayas, Rockies, Sierra Nevada, and other glaciated mountains contain lake basins which can hardly be accounted for by any other process than glacial abrasion. Striking proof of the extent of glacial abrasion is furnished

by "hanging valleys," or tributary valleys which enter a main valley at heights far above its floor, thus seeming to end in the air, as in Fig. 106. These regions also contain peculiar *cirques* or "amphitheaters" with precipitous walls curving around in a semicircle. These occur at the heads of gorges, at the meeting point of many little streams which flowed down the steep mountain side and cut little gorges separated by spurs.

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Fig. 209. — Avalanche Basin, Montana, a cirque.

These were afterward occupied by convergent névé fields and ice streams which crowded together into one main glacier. The ice cut away the spurs and gouged out the bottom, thus producing the semicircular basin.

Wind Sculpture. — Sand driven by the wind is a very efficient sculpturing tool and in desert regions accomplishes important results. Hard rocks acquire a highly polished surface, while rocks of uneven texture are etched into patterns which leave the harder portions standing out in relief. The currents are irregular in force and direc-

tion and grind out curious hollows and niches. Exposed rocks are everywhere grooved, fretted, and honeycombed (Figs. 30, 210). The bulk of the sand is lifted only a few feet, hence cliffs are attacked most rapidly at the bottom, and the upper parts are left overhanging. One striking peculiarity of wind erosion is the absence of talus slopes, the fallen fragments being continually swept away, leaving the cliffs bare to the base. The final result of wind erosion is to level the larger inequalities and to leave a plainlike surface strewn with polished boulders, which on account of superior hardness have survived the destruction of the parent ledges.

Fig. 210. — **Rock eroded by wind and sand.** (Near Laramie, Wyo.)

General Summary. — The general process of development of sculptured forms is modified in a thousand details by minor variations of climate, material, and structure. The rapidity of development increases with the rainfall and with the softness and incoherence of the material. In arid regions all forms are more angular and sharply defined, in moist regions more rounded and indefinite. Tough and compact rocks sustain themselves at sharper angles, in steeper slopes, and in higher cliffs, than loose and friable rocks. The faces of cliffs are modified by the presence or absence of *joints* or cracks which traverse most rock beds in various directions. Thick-bedded lime-

Fig. 211. — Jointed rocks and differential weathering.

stones and sandstones often present two systems of nearly vertical joints, which divide the beds into large rectangular blocks, giving them the appearance of courses of cyclopean masonry. These joints determine the planes along which the rocks split easily, so that the face of a cliff may be vertical or overhanging, according to the angle of jointing. The loftiest and most precipitous slopes occur in rocks which are practically free from joints, as in the 3300-foot granite face of El Capitan in the Yosemite Valley. In the course of weathering small local differences in the quantity of cement in a rock are etched out into curious patterns of fretwork, as shown in Fig. 211.

Fig. 212. — El Capitan.

There is one law of universal application to sculptured surfaces, — *the hardest survives.* The

level surface of a denuded plateau or mesa is generally the top of a hard bed, from which softer beds have been removed and upon which erosion has come to a comparative standstill. Streams are apt to avoid obstacles and to cut their valleys along lines of least resistance. Broadly speaking, elevated regions are, as a rule, composed of relatively resistant rocks, and depressions of relatively unresistant rocks. When the work of erosion is nearly completed, every ridge, crest, peak, spur, mesa, butte, knob, and dike stands above the average level because the material is harder; and nearly every valley, basin, gorge, clove, notch, pass, and gap sinks below the average level because the material is softer.

Influence of Mountains on Life. — The conditions upon mountains are so different from those of the surrounding lowlands that they are in many respects like islands in the sea. The upheaval of the earth-crust and subsequent erosion have brought to the surface many rocks and minerals not usually found elsewhere. Weathering goes on rapidly, but on account of the steepness of the slopes mantle rock does not accumulate. Streams are small, rapid, and not navigable. The ranges and peaks rise through the warm, dense lower air, and penetrate the upper air, which is cold, thin, and dry. Hence the temperature may vary as much from the base to the top of a mountain as from the equator to the pole. On the side toward the sea the rainfall is apt to be heavy, and on the land side to be light. This variety of conditions makes it possible for a great variety of plants and animals to exist in a small area. In some places it is possible, by ascending a mountain, to pass in one day from the luxuriant vegetation and abundant animal life of a tropical forest to a region of perpetual ice and snow. Agriculture, commerce, and

human settlement often extend up the lower slopes of mountains. Above these is a region of forest and pasture, where population is sparse, and herding, lumbering, and mining are the chief occupations.

Mountains are formidable barriers to the migration of plants, animals, and men; hence the vegetation, animal life, and people on opposite sides of a mountain range are often very different. The inhabitants of mountainous countries are, as a rule, inferior in some respects to the people of the plains. In case of invasion and conquest, the victors occupy the rich and productive lowlands, while the conquered take refuge in the mountains. There, on account of the difficulty of access and communication, they remain isolated and cut off from the general progress of the world. Sparseness of population and the hard conditions of life are unfavorable to the development of the arts of civilization. Primitive customs and habits are preserved, and the mountaineers remain relatively rude and uncultivated. At the same time, the conditions are such as to render them brave, hardy, industrious, and hospitable. They love and maintain political freedom, and escape the corrupting influences of crowded centers of population.

Lofty mountain ranges have commonly been regarded with abhorrence, as being deformities and blemishes upon the face of the earth, and the abode of evil spirits. From the time of the Romans until about a century ago, the Alps were the most efficient barrier to travel in Europe. No one visited them unless compelled by the necessities of war or commerce. A journey across them was regarded as a hardship to be avoided or endured. Interest in the lessons which mountains have to teach concerning the structure and history of the earth, and appreciation of the beauty and grandeur of mountain scenery, had their principal

birthplace in the Alps, and are chiefly the product of the nineteenth century. To-day few regions in the world have so many visitors for pleasure, recreation, and study. Switzerland and the Alps have become the playground of Europe. In the United States, the Appalachian and Rocky Mountains vie with the seashore in attraction for tourists and visitors. Every summer, thousands of people go to the mountains to enjoy pure air, cool temperature, healthful exercise, and the inspiration of wild and beautiful scenery.

CHAPTER XVII

COAST FORMS

"The sea is not satisfied with an irregular shore line, and in its attempt to reduce the land to a submarine platform it will straighten the shore line in order better to attack the land." — GULLIVER.

As the surface of the land is being continually changed by the action of the atmosphere and running water, so the restless sea is at work upon its edge, gnawing away in one place and building up in another. Hence coast lines bordering upon large bodies of water present a series of characteristic forms. The ocean basin and the continental block seem to have been permanent features from a very early period of the earth's history, but the belt on each side of the seashore has been called the *variable zone* on account of its frequent changes of level. Therefore coast lines, like relief, are primarily determined by the forces of upheaval and depression, and rising coasts and sinking coasts are distinguished by strongly marked characteristics.

Rising Coasts. — Along a rising coast the sea retreats and the new shore line is formed upon smooth sea bottom; it is comparatively regular, and may extend for thousands of miles in a series of long, gentle curves.

Sharp, narrow projections and indentations are absent, and there are seldom small bordering islands close to the shore. Such coast lines are often bordered by mountain chains, and either the slope from the mountain crest to the deep sea floor is abrupt and continuous, or only a narrow coastal plain intervenes. The Pacific coast of America between Puget Sound and latitude 40° south, and the whole coast of Africa are conspicuous examples of young and rising coasts.

Sinking Coasts. — Along a sinking coast the sea advances and the new shore line is established upon the sculptured surface of the land; hence it is irregular. The sea extends up every valley, converting it into a bay or estuary. Between the bays the ridges project into the sea as capes, promontories, and peninsulas. Numerous elevations are

Fig. 213. — Lynn Canal, Alaska, a fiord.

surrounded by water and converted into islands, which stand in front of the mainland coast. Sinking coast lands may be in any stage of sculpture and dissection; hence their shore lines present a varied irregularity.

The subsidence of the old denuded plateau of northeastern North America has broken it up into the islands of the Arctic archipelago and let the sea into the great interior basin of Hudson Bay. Newfoundland is cut off by the drowned valley of the St. Lawrence, which the sea has invaded to a distance of five hundred miles. Upon the coasts of

Norway, Alaska, and southern Chile, deeply dissected mountain ranges have sunk about half their height and let the sea into their very heart. They are now pierced by long, narrow *fiords* and canals, which are of great depths and bounded by lofty and precipitous walls (Fig. 213). These are usually shallower at the mouth and deeper inward. They resemble glaciated mountain gorges and are a joint product of stream

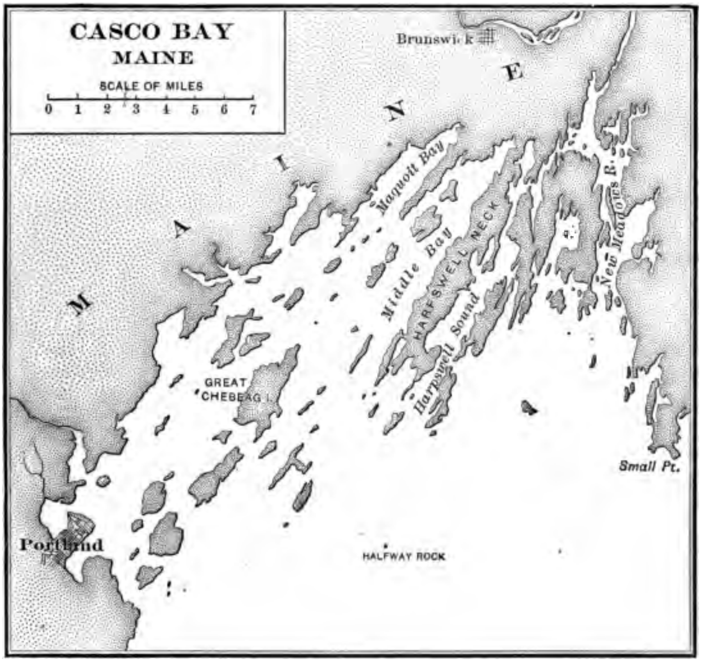


Fig. 214. — Part of the Maine coast.

and glacial erosion. Glaciated plateaus which border upon the sea, like those of Greenland and Maine, also present a fiord coast of the most ragged outline. The firths, sea lochs, and islands of the coast of Scotland are due partly to glaciation and drowning and partly to the action of waves upon rocks of varied material and complex structure.

Wave Action. — Coast lines which remain stationary at the same level for a sufficient length of time are modified

by the action of waves, currents, and tides. Waves are the chief agents of disintegration and sculpture, while tides and currents perform the work of transportation, corrasion, and deposition. The crest of a wave in shallow water moves forward with great velocity and strikes a blow against the shore. The water carried forward in the crest returns along the bottom in a current called the *undertow*. By constant repetition of this action, the edge of the land is crumbled away and a cliff is formed which varies in height with the elevation of the coast.

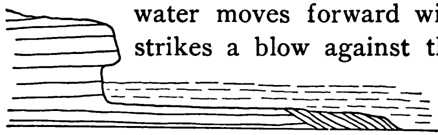


Fig. 215.

The fallen fragments are lifted, rolled over one another, and even hurled back against the cliff, until they are ground fine enough for the undertow to carry away. The erosive action of the waves, like that of a river, is greatly increased by the sediment which they carry. The dragging of the sediment back and forth over the bottom corrades the sea floor down to a level somewhat lower than the troughs of the waves. Thus waves act like a horizontal saw which makes a wide cut into the land, extending above and below the level of still water. The portion of the land above the cut breaks away and forms a *sea cliff*, along the foot of which stretches a level or gently sloping submerged platform or *wave-cut terrace* (see Fig. 215). The surface of the terrace is often diversified by small islands, reefs, and *skerries*, fragments of the cliff which were hard enough to resist erosion. In

Fig. 216.—A stack.

this process the relative hardness of the rocks plays an important part. A streak, vein, or dike of softer rock is removed more rapidly, and a ravine or tunnel is cut into the cliff by the waves. The ravines sometimes intersect, and the intervening harder blocks are separated from the main body of the cliff and left standing as sea-made buttes or *stacks* (Fig. 216).

Shore Drift. — Winds and waves seldom strike the shore at right angles, and when they strike obliquely currents are set up parallel with the trend of the coast. Such currents are intermittent, irregular, and often reversed in direction, but there is usually some prevailing direction in which the waste of the land is carried. Thus the shore drift is

Fig. 217. — A beach, Mackinac Island, Michigan.

distributed all along the coast in a zone called the *beach* (Fig. 217). The material may be sand, gravel, or boulders, and is always well rounded and partly assorted.

The beach lies partly above and partly below the level of still water, and its profile is a double curve, convex at the top and concave toward the bottom.

Where the sea bottom has a very gentle slope, the waves break at some distance from the shore and the sand they carry is deposited, forming a *barrier beach* (*B*, Fig. 218) along the line of greatest disturbance. The strip of water inclosed between the land and the barrier beach is called a *lagoon* (*L*, Fig. 218). It is often partly filled with stream sediment or wind drift and converted into a *tidal marsh*. In some

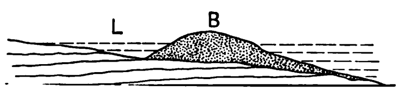


Fig. 218.

cases the shore current builds up the beach above sea level and adds to it on the seaward side, so that it gradually widens into a wave-built

terrace or *foreland* (see *T*, Fig. 219), the surface of which is traversed by parallel ridges, each the mark of some exceptionally violent storm.

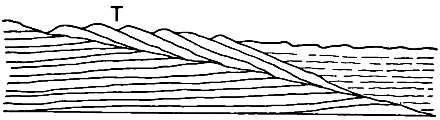


Fig. 219. — Section of a wave-built terrace.

Where the current turns away from the coast, the foreland is built out into a blunt point or *cusp*, as in Fig. 220.

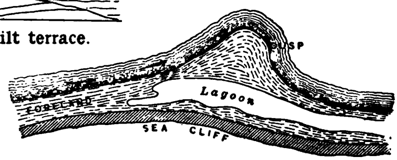


Fig. 220.

The shore current does not follow all the bends of the shore line, but sweeps across the mouth of a bay, carrying the shore drift with it. Thus a *bar* or continuation of the beach is built out from one point and sometimes extends to the opposite point, completely closing the bay. Usually, at some place in the bar, a channel is kept open by the tide or the current of a stream which empties into the bay. If the bar extends only part way across the mouth of the bay, it is called a *spit*, and when the end of the spit is recurved by some current in a different direction, it becomes a *hook* (Figs. 222, 223). A bar may extend from the shore to an island, thus tying it to the land (Fig. 224), and in some cases there are two or more connecting bars. The beach, bar, spit, and hook are only slight variants of a single form. They are at once accumulations of shore drift and roads along which shore drift is traveling. Their manner of construction is similar to that of a railroad grade along which material is transported for its own extension.

Fig. 221. — Map of bars on Lake Superior.

The Graded Plain. — The tendency of wave and current action is to cut back projecting headlands and to build

Fig. 222. — A hooked spit.

bars across the bays, thus producing a smooth shore line. If a condition could ever be reached in which the headlands were all cut back and the bays all filled, the coast

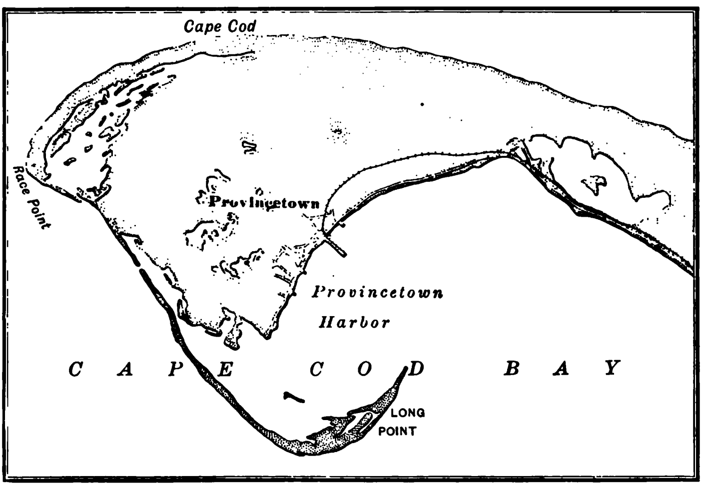


Fig. 223. – The end of Cape Cod, Massachusetts, a hooked spit.

Fig 224. – Island and bar.

line would be mature, the various forces would be perfectly adjusted, and from that time onward the sea would expend its energy in sawing into the land and reducing it to a submarine plain. In the mean time the reduction of the land surface to base level would be going on, and the product of the land-destroying forces would be a *graded plain*, lying partly above and partly below sea level, as shown in Fig. 225.

The land portion of a graded plain is gradually completed by atmospheric forces acting upon all parts of its surface at once, while the sea portion of the plain is completed strip by strip, once for all, as far as it goes. Most of the forms that are due to atmospheric forces are characterized by relief, elevation, *verticality*; most of the forms due to marine forces are characterized by *horizontality*.

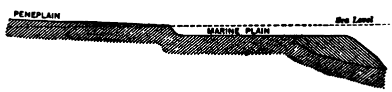


Fig. 225.

Deltas differ from all other coast forms in being the work of land streams, which build them in spite of the opposition of waves, tides, and currents. The work of a river is to convey its load of sediment to the sea and to push forward a delta lobe for each distributary. The work of the sea is to destroy this irregularity in the coast line, to cut off the lobes, and to carry the material to a *position of* rest.

In most cases the sea is stronger than the river, and well-developed deltas are exceptions rather than the rule. A stream which empties into a drowned valley builds a delta at the head of the bay and may in time fill it, thus assisting the sea in its efforts toward a smooth coast. The Mississippi delta is a typical form in which the river forces are entirely superior to those of the sea (Fig. 40). Many varieties, more or less lobed, rounded, pointed, or straight, may be found between this extreme and the opposite where the river is entirely overcome by the sea. In such cases the river is turned aside and compelled to flow a long distance parallel with the beach before finding an outlet, or its mouth is completely blocked by a straight bar, and the water escapes by percolation through the sand.

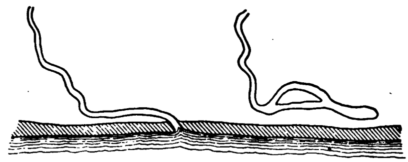


Fig. 226. — Blocked rivers.

Effect of Tides. — The general direction of tidal forces is at right angles to the coast line, and therefore at right angles to the alongshore currents which build beaches and bars. The daily flow and ebb tends to scour out bays and inlets, to break through the beach ridges, and to establish runways or channels leading across the foreland, marsh, or coastal plain.

The Eastern Coast of the United States. — The coast of North America from Yucatan to Nova Scotia exhibits, in great variety of detail, the results of the complex interaction of all the forces which shape the forms of the coast. The old Appalachian highlands have been worn down, and their débris has been spread over a belt 200 to 400 miles wide. Slow elevations and depressions have caused the shore line to swing back and forth across this belt repeatedly. Whatever position the shore line has occupied, the streams have always deposited the bulk of their sediment in the shallow water just off shore. Thus the zone of greatest deposition has swung back and forth with the shore line, and the sediment has been widely distributed. The result is a plain which slopes gently and evenly from the Piedmont plateau to the edge of the coast shelf. At the present time about half of this plain is above water and forms the Atlantic and Gulf *coastal plain*, which begins at

New York and widens southward to Texas. The other half is under water and forms the surface of the continental or coast shelf. The present shore line south of Cape Cod is for the greater part of its length double. The inner or mainland coast is indented by numerous bays, those in the north being deeper than those in the south, the result of a moderate depression which has drowned the lower portions of all the river valleys. From one to ten or more miles off the points of the mainland, the outer shore line stretches in the long, smooth, swinging curves of a barrier beach. Between the two lies a belt of lagoons, tidal marshes, and sounds. Along the Texas coast, tidal action is very feeble, and the beach is unbroken in one stretch of 102 miles. Off the great Mississippi delta the beaches are wanting or fragmentary. The form of the Florida coast is modified by the growth of coral reefs (Fig. 230). Along Georgia and South Carolina tidal action is strong, and the beach expands into the famous "sea islands," broken by many deep inlets (Fig. 229). The North Carolina coast is bordered by an almost continuous bar which extends in long curves from one cusp to another,

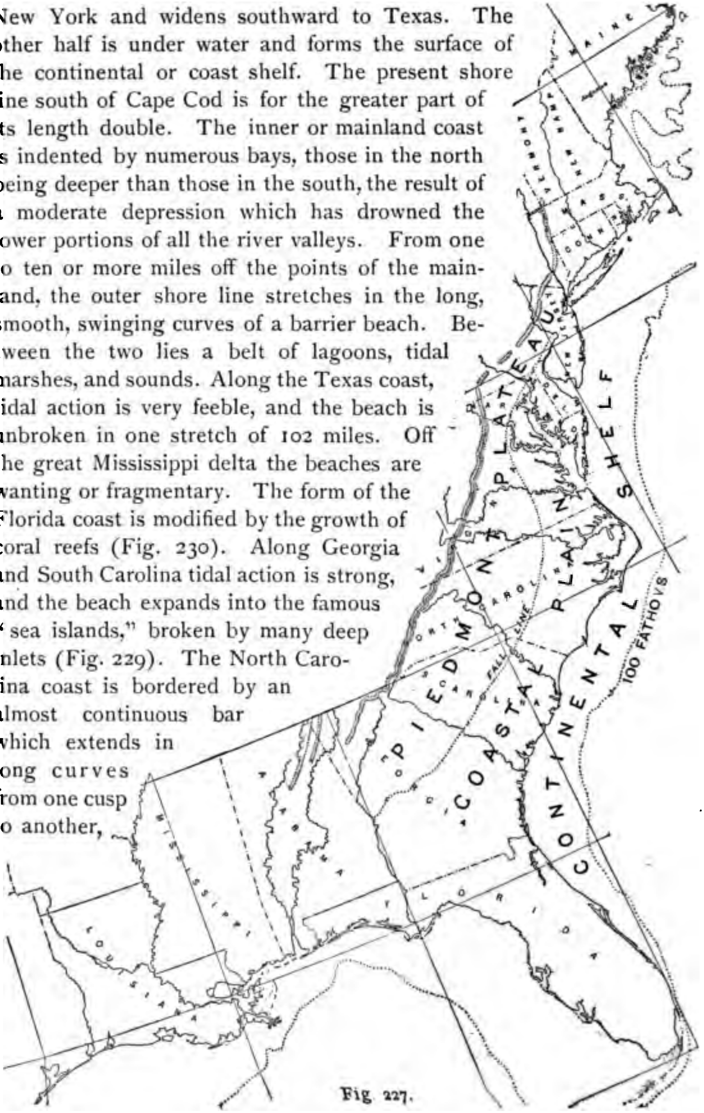


Fig. 227.

Fig. 228.

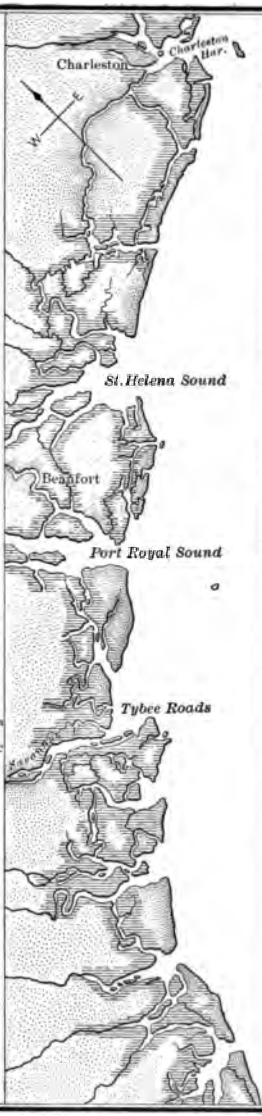


Fig. 229.

Fig. 230.

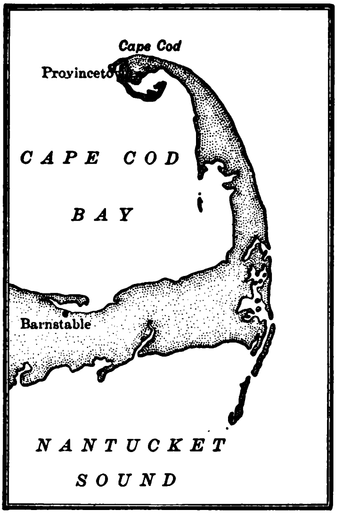


Fig. 231.

the most prominent being Capes Fear, Lookout, and Hatteras. At the north end of New Jersey the beach skirts the foot of a sea cliff and projects far into the lower bay of New York, as the spit of Sandy Hook (Fig. 228). The southern shores of Long Island, Rhode Island, Marthas Vineyard, and Nantucket exhibit an almost continuous line of lagoons and beaches. Cape Cod is an eroded headland (Fig. 231) which projects far into the sea, and from which long bars extend like wings to right and left. North of it, the characteristics of a glaciated coast become more prominent as the beaches disappear and are succeeded by the strongly contrasted coast of Maine, with its rocky islands, cliffs, and fiords (Figs. 227, 214).

Realistic Exercise. — Students who live far inland, and have no opportunity to observe forms on the seacoast, may find most of the coast forms well developed along the shores of the Great Lakes. Even a small pond or temporary pool often presents in miniature the characteristic features of wave and current action. Perhaps the most favorable opportunity for the study of coast forms is furnished by the shore lines of extinct lakes, like Bonneville (see p. 136), from which the water has retreated, leaving the bottom exposed to view. A dried-up pool beside the road will often repay careful study.

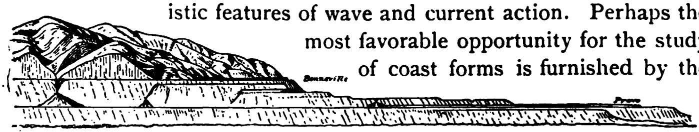


Fig. 232. – Bonneville shore lines.

CHAPTER XVIII

THE PHYSIOGRAPHIC CYCLE AND THE CLASSIFICATION OF LAND FORMS

THE present form of the face of the earth is due to the action of two sets of forces. One set, derived from the internal heat of the earth itself, produces movements of deformation in the earth-crust, or brings about a transference of matter from the interior to the exterior. The other set, derived from the heat of the sun, sets in play the various activities of the atmosphere, which are chiefly outside the earth-crust. Gravitation is the constant ally and silent partner of all. Internal forces determine the larger features, such as ocean basins, continental blocks, mountain ridges, and volcanic domes. External forces modify these by producing out of them lesser features. One set rough-hews great blocks, which the other set shapes into forms of infinite detail. To one is due the apparently boundless expanse of oceans and continental plains which give an impression of vast sameness and monotony. To the other is due an equally vast variety. One produces an island like Hawaii (see Fig. 173), which the other transforms into an island like Santa Rosa (Fig. 233). The completed work of the one consists of profound deeps and lofty heights, areas of strongly contrasted elevation; the completed work of the other would be the removal of this contrast, the lowering of elevations, the filling up of depressions, and the reduction of the face of the earth to a graded plain near sea level. Earth heat and sun heat work together, but at cross purposes: one to build up, the other to tear down.

Fig. 233.

Yet each of these processes supplements the other. The waste of the mountains and plateaus goes to form beds of sediment which fill basins and valleys, build deltas, and bury coast shelves. Igneous granite and lava are converted into clay, sand, gravel, and dissolved salts; these are consolidated into shale, sandstone, conglomerate, and limestone, and thus the total quantity of fragmental, aqueous, and stratified rock is ever increasing. These beds accumulate until they attain sufficient thickness, and are in turn upheaved to form again the massive strata of plateaus and mountains. Under the persistent stress of all these forces the materials of the earth-crust pass through a recurrent cycle of forms of which the plateau or mountainous elevation and the graded plain near sea level are the extreme members. The regular succession of changes is often interrupted and the orderly procession of forms interfered with; but every square mile of land surface is *in some stage* of development on the way from a plateau

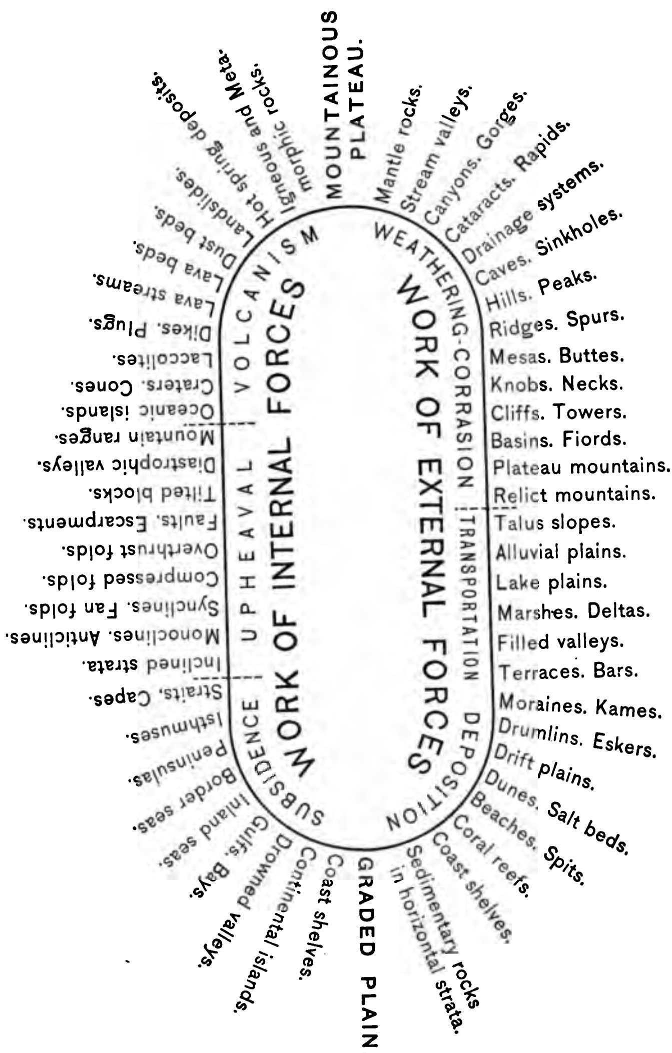


Fig. 234. — The physiographic cycle.

to a graded plain, or from a graded plain to a plateau, and its features may be readily assigned to a definite place in an ideal order which may be called the *physiographic cycle* (Fig. 234).

Classification. — The features of the land were formerly classified according to their outline, size, and superficial form, but since they have been more thoroughly studied many schemes have been proposed for their more scientific classification, according to structure and origin. No system of classification can be perfect; many features are complex in structure and the products of more than one process. There will necessarily be some inconsistencies, and some features will fall into more than one group. The following scheme is based upon origin, the forms being placed in groups according to the agents and processes which have produced them. Let the student fill out the groups indicated according to his own judgment, and suggest improvements if possible.

I. STRUCTURAL OR DIASTROPHIC FORMS, produced by deformation or dislocation of the earth-crust.	By upheaval. By subsidence. By fracture. By folding.
II. ACCUMULATED FORMS, produced by the deposit or heaping up of material.	By running water. By ice. By wind. By waves, tides, and currents. By volcanism.
III. SCULPTURED FORMS, produced by the removal of material.	By weathering. By running water. By ice. By wind. By waves, etc.

BOOK III. THE SEA

I am the Sea! I hold the land
As one holds an apple in his hand;
Hold it fast with sleepless eyes,
Watching the continents sink and rise.
Out of my bosom the mountains grow,
Back to its depths they crumble slow.
The iron cliffs that edge the land
I grind to pebbles and sift to sand;
I comfort the earth with rains and snows
Till waves the harvest and laughs the rose.
Flower and forest and child of breath
With me have life — without me, death.
The earth is a helpless child to me.
I am the Sea!

— CHARLOTTE PERKINS STETSON.

CHAPTER XIX

THE FIGURE OF THE SEA

THE sea is an irregular, incomplete, spheroidal shell of water which covers about 72 per cent of the earth-crust, intervening between it and the atmosphere. The upper surface of the sea is convexly curved and comparatively smooth, while its lower surface conforms to the elevations and depressions of the earth-crust, and is irregular. Its thickness varies from zero to nearly six miles, averaging about two and one fifth miles. Compared with the size of the earth, the sea forms upon it only an insignificant film; but the volume of the sea is nearly thirteen times that of the land above sea level. If all the land were shoveled into the Atlantic, it would fill only one third of that ocean.

Oceanography, the science which treats of the sea, has come into existence only since the middle of the nineteenth century.

While the general outline of the oceans has been known since the voyages of Cook (1768–1779), very little progress had then been made in the exploration of the sea bottom and the study of the properties and movements of sea water. Successful soundings in deep water were first made by Sir John Ross in 1840. He was also the first to dredge up material from the deep sea floor.

Special apparatus designed for deep sea exploration has now reached a high degree of efficiency. Depths of the ocean are measured by means of a steel wire to which an iron tube is attached. The tube passes through a lead or iron weight hung upon a hook in such a manner that when the tube strikes the bottom the weight drops off. The tube is fitted with devices for bringing up specimens of water and mud from the bottom. At intervals along the wire, thermometers are attached which record the temperatures of the water. Dredges and nets of various kinds are dragged along the bottom to catch the animals which may be present.

The greater part of our knowledge of the sea below the surface was obtained during the voyage of the *Challenger* (1872–1876), a ship fitted and sent out by the British government for the purpose of surveying the ocean basins. The *Blake* of the United States Coast Survey and vessels of other nations have made thorough explorations of limited portions of the sea, so that some areas of the sea bottom are now more accurately known than many areas of the land surface.

The Surface of the Sea.— The "level of the sea," although not constant or uniform, is the standard from which all geographical heights and depths are measured.

The centrifugal force of the earth's rotation tends to make the surface of the sea conform to that of a spheroid which is about thirteen miles farther from the center at the equator than at the poles; but the constancy and uniformity of this spheroidal surface are disturbed by many causes: —

(1) The attraction of the land masses tends to make the sea surface higher near all coasts, especially mountainous coasts, than in mid-ocean.

(2) Ocean currents and on-shore winds tend to pile up the waters in deep bays in their course.

(3) In regions of heavy rainfall, as in the equatorial rain belt, the

surface of the sea probably stands higher than in regions where evaporation is rapid, as near the tropics.

(4) Differences in atmospheric pressure in adjacent regions causes differences in sea level in those regions. Thus in the center of a tropical hurricane, the low pressure and inblowing winds heap up the water to a height which, when it occurs near shore, proves very destructive as the water sweeps over the land.

(5) Sedimentation is constantly filling up the ocean basins and tending to raise the sea level, while movements of the earth-crust may change its level either up or down.

(6) The winds cause waves, and the attraction of the sun and moon causes tides which disturb the surface of the sea.

The Ocean Basins. — The sea is divided by the land masses into four basins of unequal size and widely varying outline (see map, pp. 40, 41).

The Basin of the Pacific Ocean comprises about 40 per cent of the whole sea area. It is roughly circular in outline, with a diameter of about 10,000 miles. The main body of the Pacific Ocean has an average depth of two and three fourths miles.

The Pacific is nearly closed at the north in latitude 65°, Bering Strait being both narrow and shallow. At the south it opens widely into the Southern Ocean. Its bed is traversed by numerous ridges which have a general northwest and southeast trend, and bear upon their tops thousands of small volcanic islands. It also contains several remarkable deeps. Fifty miles off the coast of Peru a sounding of 25,000 feet has been made, in the Tuscarora deep east of Japan one of 27,930 feet, in the Aldrich deep northeast of New Zealand one of 30,930 feet, and in the Challenger or Nero deep south of the Ladrone Islands, the deepest sounding yet reported, 31,614 feet, or nearly six miles. The Pacific shore line on the American side is for the most part regular, and the slope from it abrupt. The northern and southern extremities are indented by numerous fiords. Along the northern and western sides of the ocean, peninsulas and lines of islands parallel with the coast inclose a continuous series of *border seas*.

The Basin of the Atlantic Ocean comprises nearly one fourth of the sea area. Its length is 9000 miles, and its

Fig. 235. — Cross section of the Atlantic.

least breadth between Africa and South America about 1700 miles. Together with the Arctic and Antarctic oceans it affords a broad channel of communication almost from pole to pole. The average depth of the main body of the Atlantic Ocean is about two and one half miles.

The bottom is traversed lengthwise by an S-shaped central ridge over which the water is less than 12,000 feet deep. This ridge separates two valleys or troughs 15,000 to 20,000 feet deep, one extending along the American coast, and the other from the British Isles southward. At latitude 40° south the ridge ends, and the two valleys unite in a broad basin which penetrates far into the Antarctic regions and sinks on the polar circle to a depth of 25,000 feet. At the north the Atlantic basin is separated from the Arctic by a ridge which extends from the British Isles to Greenland and rises to a level less than 3000 feet below the surface. The greatest depth known in the Atlantic is 27,366 feet in the Blake deep near Porto Rico. Connected with the Atlantic are many *inland seas* of the largest size, the Mediterranean, Black, and Baltic on the east, and Hudson Bay and the Gulf of Mexico on the west; while the Caribbean and North seas belong to the class of border seas.[1] The coast shelf along the shores of the Atlantic is generally wide except on the African coast.

The Basin of the Indian Ocean comprises about one eighth of the sea area and is in the shape of a triangle with a notch at its apex. Near the African coast it is broken by the large island of Madagascar, and its bottom is studded with numerous volcanic peaks, some of which rise above the surface. The main body of the Indian Ocean has an average depth of two and one fourth miles.

The Basin of the Arctic Ocean comprises only about one thirtieth of the sea area and is nearly inclosed by the great northern land masses whose

[1] Inland seas are nearly inclosed by continents; border seas by islands.

shores surround it at about the seventieth parallel. Greenland projects northward beyond 80°. An opening about 1200 miles wide between Europe and America connects the Arctic with the Atlantic. The depth of the Arctic north of Eurasia was found by Nansen to be over 12,000 feet. A great part of it is covered by drifting ice.

The Southern Ocean is only a convenient term to designate that part of the sea south of the fortieth parallel, from which the three great oceans diverge northward. It forms about one fifth of the sea area, and its average depth is more than two and one fourth miles. The region within the Antarctic circle is mostly occupied by a land mass or archipelago buried under an ice cap of great thickness (see p. 120).

Origin. — The ocean basins not improbably owe their existence to differences in the original composition of the earth. According to the contraction theory (see p. 48), the earth has cooled and contracted more rapidly along some radial lines than along others. Those regions where radial contraction has been greatest are depressed. According to the theory of isostasy, the earth-crust under the oceans is denser and heavier than under the continents, and has consequently gone down. Both theories imply that the ocean basins were formed at a very early period of the earth's history and have been permanent ever since — a conclusion which is sustained by considerable direct evidence (see p. 249).

The Sea Floor. — The surface of the sea floor, being protected from the atmosphere, is free from all those features which are produced by erosion. Stream valleys, so common upon the land, are absent on the sea bottom except upon those portions of the coast shelf which were formerly exposed above sea level. Precipitous cliffs and

escarpments, probably due to faulting, have been discovered in some localities near the continents, but on the floor of the open sea generally the slopes are so gentle that a railroad could be run across it without grading or bridges. Of the structure of the sea floor, nothing is known except that volcanic cones seem to be more numerous than upon land. The floor is covered to an unknown depth with unconsolidated sediments of various kinds.

Fig. 236. — Continental deposit.
(Magnified 10 times.)

Continental Deposits. — The waste of the land is brought down by streams and spread over the sea bottom by waves and currents. The coarsest sediment is deposited near shore, but the finest may be carried out several hundred miles. This material is easily recognized by the worn and rounded shape of its particles. Judging from the depth of similar deposits revealed by boring on the coastal plains, it probably attains near the land a thickness of several thousand feet. It covers about 14 per cent of the area of the sea bottom.

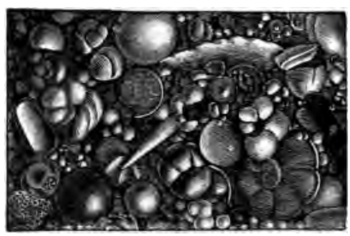


Fig. 237. — Globigerina ooze.
(Magnified 13 times.)

Organic Deposits are being laid down everywhere on the sea floor. They consist of the shells and other hard parts of marine animals and plants. Every organism in the sea which has a shell or bony skeleton contributes something to this deposit, but the bulk of it is made up of the shells of minute animals which live near the surface. As they die, their shells are continually falling through the water, like a gentle snow-

storm, and accumulate on the bottom as a soft, gray, chalky ooze. Under the microscope this ooze may be divided into several varieties according to the preponderance of the shells of certain species or families, as globigerina ooze, pteropod ooze, diatom ooze, etc. Most of the shells are composed of carbonate of lime, but the diatom ooze consists of the siliceous cases of microscopic plants, which flourish in the cool and relatively fresh waters of the Southern Ocean. The lime deposits cover about 35 per cent, and the silica deposits about 7 per cent of the sea floor.

Red Clay. — On the deepest parts of the sea floor the organic ooze disappears, and the surface is covered by a fine, sticky, red clay which becomes very hard when dry. Under the microscope it is found to contain sharp, angular grains of volcanic dust. It is also in part made up of the insoluble residue of organic deposits. As the shells settle through the water, they gradually dissolve until all the lime disappears and only the insoluble matter remains.

Fig. 238. – Red clay. (Magnified 100 times.)

Along with the red clay occur great numbers of sharks' teeth which have resisted the solvent action of the sea water, and many irregular, rounded nodules of manganese of all sizes up to several inches in diameter. Many of the teeth belong to species which are now extinct, and must have lain upon the sea bottom for untold ages without being covered up by the clay. The manganese lumps have been formed very slowly from the minute quantities of that element which exist in solution in sea water, and are indications of the long period of time during which the depths of the sea have existed under conditions substantially the same as at present. The red clay covers about 35 per cent of the sea floor.

CHAPTER XX

SEA WATER

"We have in imagination been disposed to regard the waters of the sea as a great cushion placed between the air and the bottom of the ocean to defend and protect it from the abrading agencies of the atmosphere." — MAURY.

Composition. — The ocean basins are filled with water which contains about $3\frac{1}{2}$ per cent of mineral matter in solution. More than three fourths of this is common salt, probably derived from the primitive atmosphere, which was hot enough to contain the water and salt in the form of vapor. The other minerals consist of salts of lime, magnesia, and potash, and minute quantities of almost every known element, all of which may have been brought into the sea from the land by rivers. The average composition of the salts of sea water is given in the following table: —

Sodium chloride (common salt)	77.758
Magnesium chloride	10.878
Magnesium sulphate	4.737
Calcium sulphate	3.600
Potassium sulphate	2.465
Magnesium bromide	0.217
Calcium carbonate	0.345

Sea water also contains the gases of the atmosphere dissolved in proportions which vary with the pressure and solubility of the gases, with the depth and temperature of the water, and with other conditions not fully understood. They are absorbed from the air at the surface and distributed through the depths by the movement of the water. They are subject to increase and decrease by the action of animal and plant life and by other chemical processes. The quantity of oxygen diminishes with increasing depth. The quantity of carbon dioxide increases as the temperature falls, and is greatest in the bottom waters.

Temperature. — The rays of the sun do not penetrate the sea to a greater depth than about 600 feet. Consequently the deep water, comprising by far the greater part of the whole sea, has a constant temperature at any given spot throughout the year, while the surface water is subject to seasonal and occasional changes of temperature.

The map, p. 253, shows isothermal lines drawn through places of equal surface temperature. A mean annual surface temperature of 80° or above is found in a belt about thirty degrees wide lying on both sides of the equator in the Indian and western Pacific, and a much narrower belt lying north of the equator in the Atlantic and eastern Pacific. A mean annual surface temperature below 40° is found in the Arctic, the extreme northern Pacific, the Atlantic north of Newfoundland, Iceland, and Norway, and the Southern Ocean south of latitude 55°.

The surface of the ocean may be divided into five great zones of temperature: (1) an intertropical zone with high temperature, 70° to 90°, and a range or seasonal variation of less than 10°; (2 and 3) two circumpolar zones with a temperature below 40° and a range of less than 10°; (4 and 5) two intermediate zones with a range amounting to 20° to 50°. The lowest recorded temperature of surface water in the open ocean is 29° near the Faroe Islands, and the highest 90° in the equatorial Pacific. The Red Sea and Persian Gulf sometimes reach 94° and 96°. About 13 per cent of the sea surface has a temperature always below 40°, and about one half has a temperature always above 60°.

The temperature of the deep bottom water is everywhere low, varying from 29° in the polar regions to 35° under the equator. In the equatorial regions the temperature falls rapidly with increasing depth from the surface to 40° at 2000 to 4800 feet, then slowly to the bottom. If we call the water above 40° warm, then the layer of warm water is nowhere more than 4800 feet thick, and in most places considerably less. Ninety-two per cent of the sea

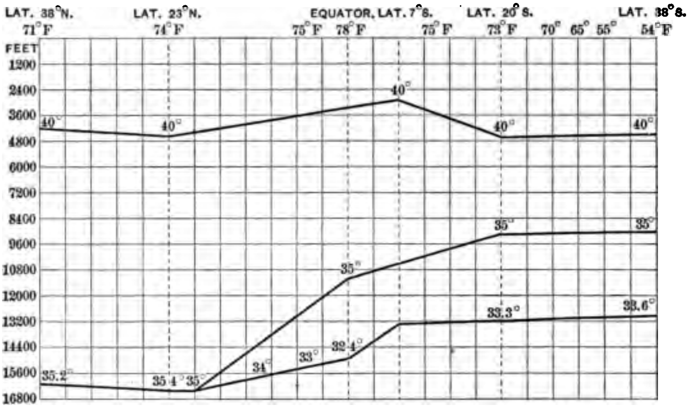
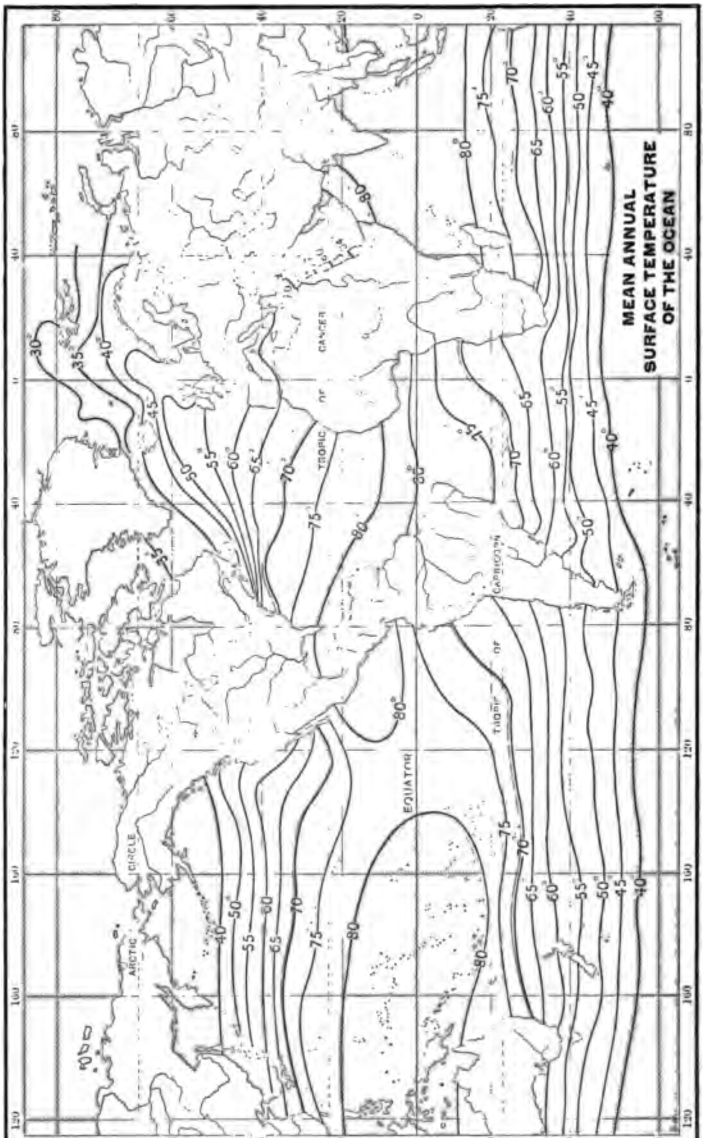


Fig. 239.—Section of the Atlantic Ocean, showing temperatures.

floor is overlain by water having a temperature below 40°, while only three per cent of the floor has a temperature always above 60°. Eighty per cent of all the water in the sea is below 40°, and the average temperature is between 38° and 39°.

The sun has been shining upon the sea for many millions of years, and, although its rays do not penetrate deeply, there has been time enough for the heat to reach the bottom by the slow process of conduction. It might also be expected that the internal heat of the earth would do something toward keeping the lower waters warm. The fact that while the temperature of the earth-crust increases downward, the temperature of the sea decreases in the same direction, constitutes one of the most interesting problems of oceanic geography. The Mediterranean Sea is a large body of deep water (13,000 feet) shut off from the ocean by a barrier at the Strait of Gibraltar which rises to a level of 1200 feet below the surface. The temperature of the Mediterranean water falls from 75° at the surface to 55° at a depth of 750 feet, where it ceases to fall and remains constant at 55° all the way to the bottom. The temperature of the Atlantic water outside falls continuously from 75° at the surface to 37° at the bottom. The Red Sea has a temperature of 70° from 1200 feet to the bottom at 3600 feet. Here nature has contrived a suggestive experiment for us on a large scale by


MEAN ANNUAL
SURFACE TEMPERATURE
OF THE OCEAN
ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN

confining a body of deep water and showing that it can be kept warm to the bottom. It is also true of the Gulf of Mexico and other inclosed bodies of water, that their bottom temperature is about the same as that of the bottom of the deepest inlet from the ocean. The lesson plainly is that the low bottom temperatures of the open sea are due to a circulation which carries the cold polar waters along the bottom toward the equator, where they rise, become warmed, and evaporate or return toward the poles on the surface. The shallowness of the warm water at the equator is explained by the rise of cold water from the bottom. The escape of any considerable quantity of cold water from the Arctic basin is prevented by the shallowness of the openings, but the basins of the Atlantic, Pacific, and Indian may be regarded as great gulfs opening from the Southern Ocean, which acts as a refrigerator and controls their bottom temperatures, making them lower in the southern than in the northern part of each. The movement is not in the nature of a current, but a creep of the whole lower mass of water so slow that it does not stir the finest sediment, and is discoverable only by its effects upon temperature. It is probably supplied by a sinking of the water at about 50° south latitude, where the cold Antarctic and salt tropical waters meet. Figure 240 shows the effect upon temperature of a ridge in the ocean bottom. The northward movement of the water is so slow that it is stopped by the barrier, and the bottom temperature on the north side of it is no lower than the temperature at the level of its top.

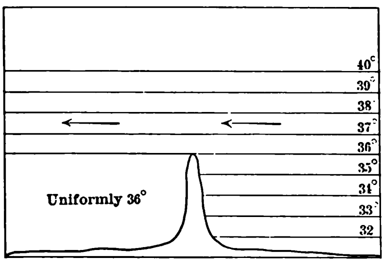


Fig. 240.

Average Temperature of the Sea at Various Depths

Depth	Temperature
600 feet	60.7°
1,200 "	50.0°
3,000 "	40.1°
6,000 "	36.5°
13,200 "	35.2°

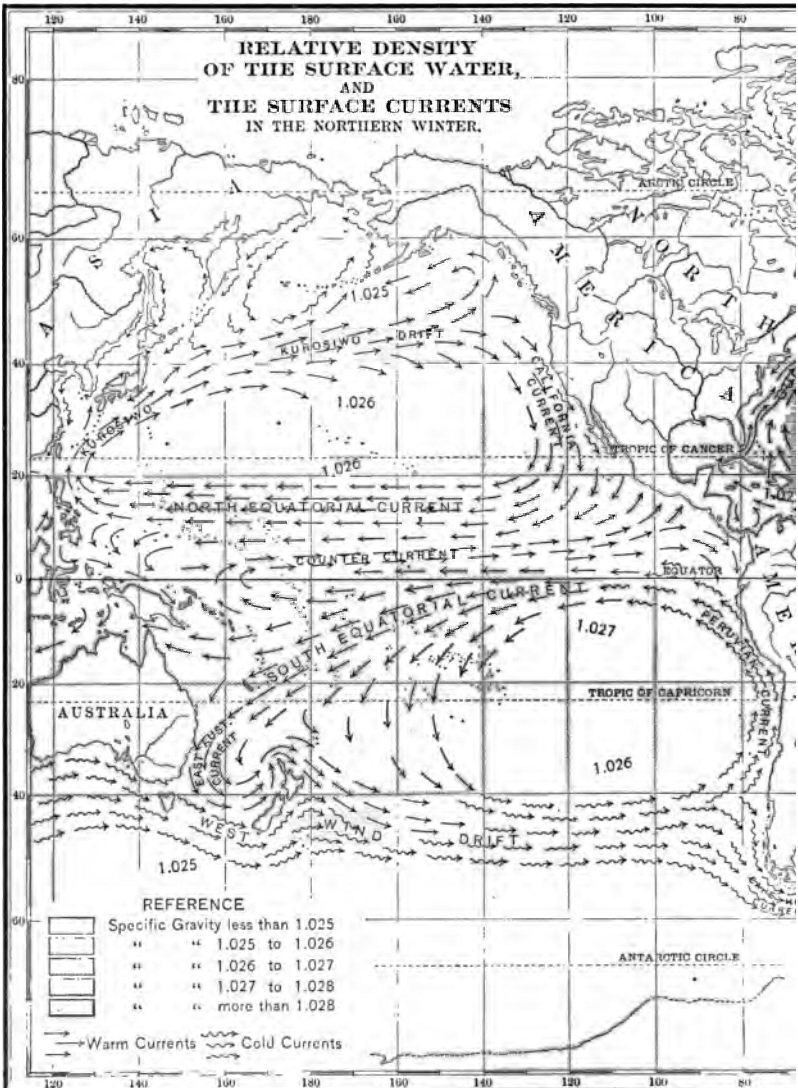
Pressure and Density. — The pressure of a liquid is equal in all directions and proportional to its depth. The pressure of sea water one foot deep is 0.445 pound upon every square inch of surface. At the depth of a mile the pressure is 2350 pounds, or the pressure of sea water is more than one ton per square inch per mile of depth. The pressure at a depth of five or six miles would crush a hollow vessel of almost any material if it were not sustained by pressure within.

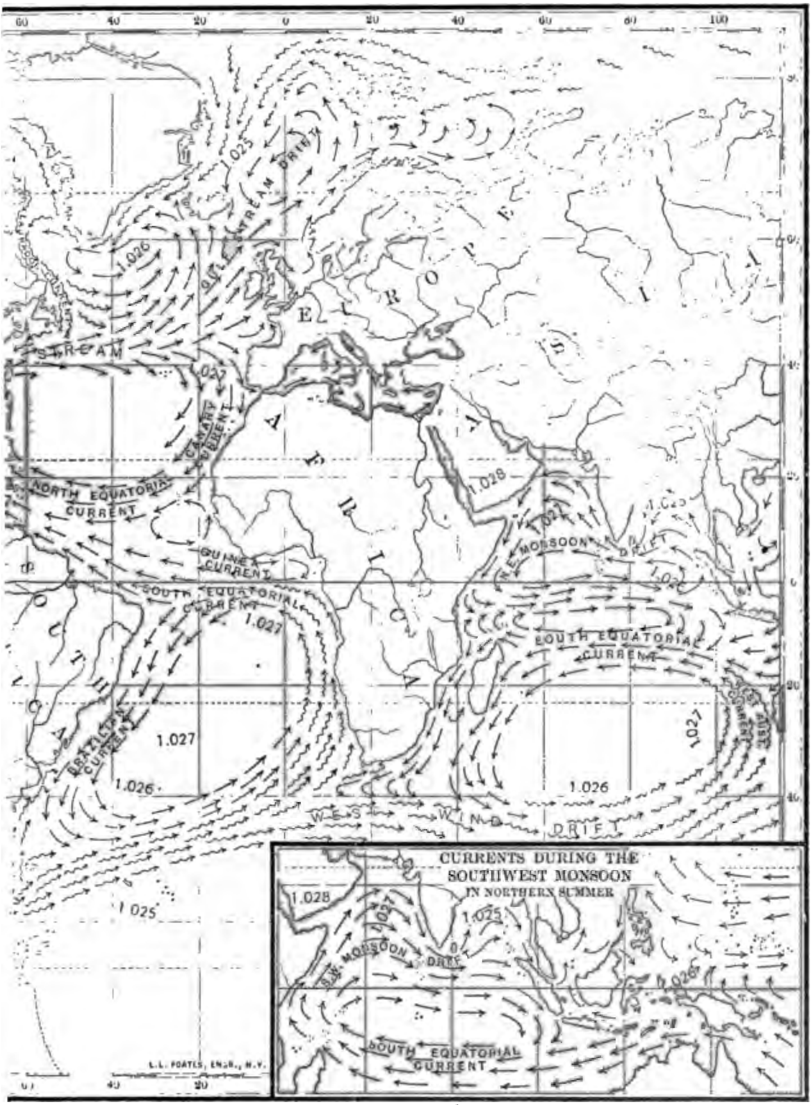
Deep-sea thermometers have to be protected from pressure. A sealed glass tube containing air, lowered to a depth of 12,000 feet, was crushed to a fine powder. If water were easily compressible, its density at great depth would be greatly increased by the pressure of the water above. Water is but slightly compressible, so that 140 cubic feet of surface water lowered to a depth of one mile would be compressed to 139 cubic feet, and at a depth of five miles its density would be increased 3½ per cent. The density of surface sea water varies with the temperature, but depends chiefly upon the quantity of salts held in solution. It is greatest in the tropical regions of rapid evaporation, and least in the equatorial region of heavy rainfall and the polar regions of freezing and melting ice (see map, pp. 256, 257).

DENSITY OF WATER UNDER VARIOUS CONDITIONS

Pure water at 39.6° F.	1.00
Surface sea water at 60° F.	1.024 to 1.03
Sea water at a depth of five miles	1.06
Pure water at 212° F.	.95
Pure ice	.92
Sea ice (with included air) about	.9175

On account of the low temperature and high pressure in the depths of the sea, the density of the water there must be considerably higher than that due to its saltness alone. To ascertain the actual density of the water, the density determined after the water has been raised to the surface must be corrected according to the temperature and pressure which exist at the depth from which it was taken. When this is done, it is found that the water lies in quite regular horizontal layers which increase in density downward.


RELATIVE DENSITY
OF THE SURFACE WATER,
AND
THE SURFACE CURRENTS
IN THE NORTHERN WINTER.
ASIA
NORTH AMERICA
AUSTRALIA
ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ANTARCTIC CIRCLE
KUROSIWO
KUROSIWO DRIFT
CALIFORNIA CURRENT
NORTH EQUATORIAL CURRENT
COUNTER CURRENT
SOUTH EQUATORIAL CURRENT
PERUVIAN CURRENT
EAST AUST. CURRENT
WEST WIND DRIFT
1.025
1.026
1.026
1.027
1.026
1.025
REFERENCE
Specific Gravity less than 1.025
" " 1.025 to 1.026
" " 1.026 to 1.027
" " 1.027 to 1.028
" " more than 1.028
Warm Currents
Cold Currents


CURRENTS DURING THE
SOUTHWEST MONSOON
IN NORTHERN SUMMER
NORTH EQUATORIAL
CURRENT
GUINEA CURRENT
SOUTH EQUATORIAL
CURRENT
CANARY CURRENT
BRAZILIAN CURRENT
STREAM
STREAM DRIFT
N.E. MOSSOON
DRIFT
S.W. MOSSOON
W. E. S
W I N D
DRIFT
L. L. POATES, ENGR., N.Y.

CHAPTER XXI

MOVEMENTS OF THE SEA

"No drop of the ocean, even at its greatest depth, is ever for one moment at rest." — WHARTON.

Waves may be produced by any disturbance of the sea surface, but they are usually the result of the friction of the wind. Waves are a series of parallel ridges and hollows which follow one another across the surface of the water. The parts of a wave are *crest* and *trough;* and the dimensions are *length,* or the distance from one crest to another, and *height,* or vertical distance from the bottom of the trough to the top of the crest. Each wave appears to consist of a mass of water moving forward in the direction of the wind, but, except in shallow places, the water moves forward and back and up and down. The wave moves forward by taking in continually new water in front and dropping out water behind. The motion may be imitated by shaking a sheet or strip of cloth up and down; waves pass through it from end to end, but no portion of the cloth travels lengthwise. A flag blown out from the staff and waving in the wind performs similar vibrations.

The movement of the water in a wave is not quite so simple as that of the cloth and is shown in Fig. 241.

The line *AB* represents the surface of a water wave whose length is *ai,* moving in the direction of the long arrow. Suppose the wave length to be divided into eight equal parts, *ab, bc,* etc. If the water were still, the particles 1, 2, 3, etc., would lie directly above the points *a, b, c,* etc., but each particle is moving in a circular path in the direction shown by the curved arrows. Particle 9 is at the lowest point, 8

has moved one eighth of a circle farther than 9, 7 one eighth farther than 8, etc., 5 being half a revolution farther along than 9 and at the highest point. When the wave has advanced one half its length, each particle will have moved through one half a circle, 1 and 9 will be at the crest, and 5 at the bottom of the trough. Thus while the wave advances its whole length each particle of water makes a complete revolution. As shown by the small arrows, the column of water under the trough is moving backward, the column under the middle of the front slope up-

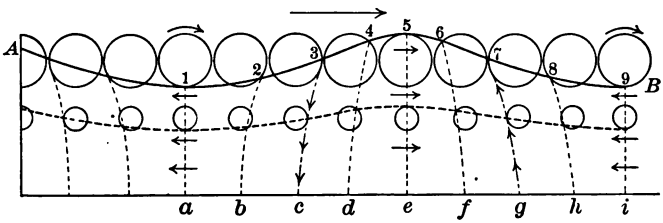


Fig. 241.

ward, the column under the crest forward, and the column under the middle of the back slope downward; but the distance moved diminishes with the depth as shown by the small circles. If the water were at rest, the dotted lines *a*1, *b*2, etc., would all be vertical and the columns of water inclosed by them would be of uniform width; but in the wave motion the lines sway back and forth, like the stalks of grain in a field when the wind blows, and the columns under the troughs become wider at the top, and the columns under the crests narrower. By the rise of the water the crest is continuously transferred to a point in front of its position at any given moment, and the trough is transferred in the same direction by the fall of the water. The path of a particle is not always circular, but varies with the form of the wave. It is often an ellipse with its long axis inclined or horizontal.

The surface of the sea is never still. When the air is calm the influence of previous winds or of distant storms keeps up a long, low undulation called the *ground swell.* Storm waves sometimes reach a height of 50 feet and a length of 1500 feet, and travel 60 miles an hour. As waves approach the shore and reach shallow water, there is not water enough to build up the front half to its full

dimensions, the front slope becomes steeper than the back slope, then perpendicular, and finally overhanging until the crest falls forward, forming a *breaker*. On shelving shores the waves sometimes rise to a height of 100 feet or more, and the crests, containing many tons of water in rapid forward motion, strike blows which hardly anything can resist. Cliffs are pounded to pieces, lighthouses destroyed, and breakwaters built of the heaviest masonry washed away. The pressure sometimes reaches 2000 pounds per square foot.

Fig. 242. — A breaker.

Tides. — The level of the sea is subject to a regular, periodic rise and fall which is called the tide. It varies in amount at different places. On the deep, open ocean it is probably less than one foot. On the coasts of oceanic islands it is not more than six or seven feet, while at the heads of funnel-shaped inlets, like the Bay of Fundy, it amounts to as much as fifty feet. If we should watch the tide from any point along the coast at low water, we should see the rocks, bars, and portions of the beach and sea bottom laid bare; then the water would slowly *flow* or creep up for several hours and cover them. High water would be

followed by an *ebb* or fall, lasting six hours or more. The interval between two periods of high water or low water is twelve hours and twenty-six minutes, but it is not always equally divided between ebb and flow,

Fig. 243. — Low tide.

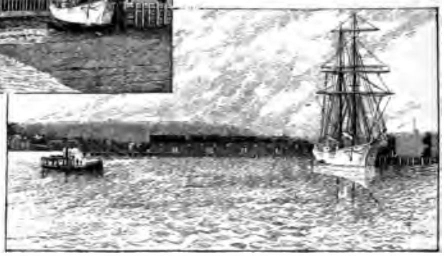


Fig. 244. — High tide.

the rise being generally more rapid than the fall.

The difference of level between high and low water varies not only at different places, but at different times at the same place. These phenomena must have been observed by all peoples who have lived along the shore of the sea, and it must have been noticed at a very early period that the times of high and low water have some relation to the position and phases of the moon. The connection between the moon and the tides was not understood, however, until Newton's discovery of the law of gravitation.

If the earth were a globe of water, it is easy to understand how the attraction of the moon would draw it out of shape and produce a slight elongation or bulging in the direction of the moon. The effect upon the spheroidal shell of sea water is the same as though it were a complete sphere.

Realistic Exercise. — Fill a toy balloon with water, but not too full, and fasten a cord to its neck. A gentle pull upon the cord will cause the sphere to become elongated. Swing the balloon around in a horizontal plane and the long axis will become horizontal.

To produce this effect there must be two forces acting in opposite directions. We commonly think of the moon as revolving around the

earth, but the exact truth is that the earth and moon revolve together around their common center of gravity. If the earth and moon were connected by a rigid bar without weight, but strong enough to support both, the point in the bar where they would balance would be the center of gravity. Although the bar would be 240,000 miles long, the earth is so much heavier than the moon that the center of gravity falls within the mass of the earth about 3000 miles from the center. The earth and moon revolve around this point once in about twenty-eight days. If it were not for the centrifugal force generated by this revolution, the mutual attraction of the two would cause them to fall together, and their distance from each other is determined by the exact balancing of these two forces. At the center of the earth the balance is perfect, but on the side of the earth which is nearest to the moon attraction is a little stronger than at the center, and causes the water to bulge slightly toward the moon. On the side of the earth which is farthest away from the moon the attraction is a little weaker than at the center, and the unbalanced centrifugal force causes the water to bulge slightly away from the moon. In Fig. 245 *G* is the common center around which the earth and moon revolve. The arrows indicate by their length the

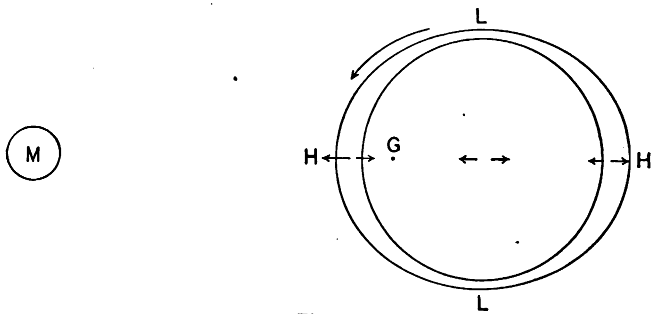


Fig. 245.

relative values of the two forces at the places in question. Thus there are at any given moment two places of high water, *H*, on opposite sides of the earth and two places of low water, *L*, between them.

If the moon were always above the same point on the earth, there would always be high water at that point, the moon would cause no change in the level of the sea anywhere, and, consequently, there would be no lunar tides;

but, as the earth rotates on its axis from west to east, the point directly under the moon and the other points of high and low water travel around the earth from east to west at the same rate as the apparent motion of the moon.

Thus every part of the sea has two stages of high water and two of low water within the time between two transits of the moon over any given place (24 hours and 52 minutes). The period is more than twenty-four hours, because the moon is actually moving in its orbit eastward in the same direction as the rotation of the earth, and after one rotation of the earth on its axis, it takes fifty-two minutes for any given point on the earth to overtake the moon.

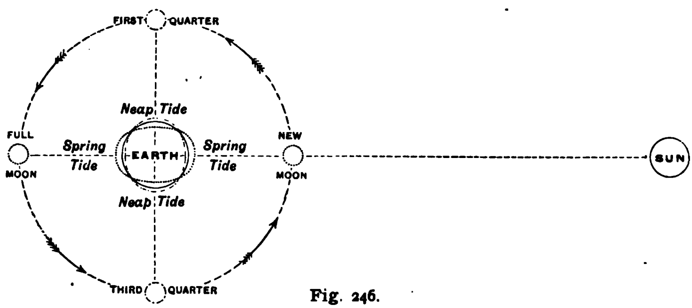


Fig. 246.

The sun also produces tides in the sea in the same manner as the moon, but on account of its greater distance the solar tides are much smaller than the lunar. At new moon and full moon the sun, earth, and moon are all in the same straight line, as shown in Fig. 246, and the lunar and solar tides combine to produce a greater rise and fall than usual, called *spring* tide. At intermediate periods the sun and moon act at right angles to each other and produce a smaller rise and fall than usual, called *neap* tide.

The variations in the moon's path and distance, the form and depth of the ocean basins, the outline of the continents, and the configuration of inlets produce endless variations in the height and period of the tides. The rise and fall are greatest at the heads of open-mouthed bays, where the crest of the tidal wave finds less and less room as it progresses

toward the head, and least in landlocked seas like the Mediterranean and Gulf of Mexico.

The tidal movement in the north Atlantic seems to be a slopping of the water back and forth as in a tilted basin, high water occurring on the west side at the same time as low water on the east. In straits connecting two bodies of water which receive the tidal wave at independent mouths, as in East River between New York Bay and Long Island Sound, high water does not occur at both ends at the same time, and powerful and sometimes dangerous currents, called *races*, flow alternately in

Fig. 247. — Bore, on the Seine River.

opposite directions. Where the tide enters the mouth of a river, the water sometimes piles up into a wave with perpendicular front which travels upstream at high speed, washing away the banks and upsetting or filling boats. Such waves are called *bores*, and are especially notable in the Amazon, Seine, and Severn rivers.

Currents. — The surface waters of the sea are not only subject to the to-and-fro movement of waves and tides, but also take part in a vast system of circulating currents by which the water is transferred to distant regions, temperature and saltness are partly equalized, and the climate of

the land masses is greatly modified. The map on pp. 256, 257 shows the location, direction, and extent of the principal surface currents. The largest members of the system or trunk streams of each ocean basin extend parallel with the equator on each side of it.

In the Pacific the North Equatorial current starts from the west coast of Mexico and flows westward about 8000 miles. Its width is 600 miles, its depth about 600 feet, and its velocity averages one mile per hour. The volume of water in motion is several hundred times greater than that carried by the largest river on land. It reaches the continental barrier at the Philippine Islands, where it divides, and the larger branch turns northward and eastward past the Japan Islands, where it is called the Kurosiwo or Japan current. In middle latitudes this current returns eastward across the north Pacific to the coast of North America. A large branch forms a reversed eddy along the coast of Alaska, but the greater part flows south, and, completing the circuit, rejoins the Equatorial current.

The South Equatorial current leaves the west coast of South America and flows westward 4000 miles without interruption. In mid-ocean it encounters the submarine ridges of the southwestern Pacific and sends numerous branches southward. A part of its water finally reaches Australia and flows south along the eastern coast. All these branches finally join the Antarctic drift, which moves eastward around the globe between 40° and 60° south latitude, and some portion of the water, following the coast of South America northward, completes the circuit. Between the two westward-flowing equatorial currents a small Counter current, made up of branches from either side, flows back eastward and completes an independent circuit.

In the Atlantic Ocean the North Equatorial current leaves the coast of Africa and moves westward to the West Indies, where it is joined by a large branch from the South Equatorial current. A portion of the combined streams passes through the Caribbean Sea and Yucatan channel, rounds the western end of Cuba, and emerges from Florida Strait as the Gulf Stream. A larger portion flows between and outside of the West India Islands and joins the Gulf Stream east of Florida and Georgia. The combined currents are here seventy-five miles wide with an average velocity of four miles per hour, and sweep the bottom at a depth of 2500 feet. The Gulf Stream follows the coast of the United

States as far as Cape Hatteras, where it leaves the land and crosses the ocean to the vicinity of the Azores Islands. Here it divides, a part returning southward and completing the circuit, while a greater part, spreading out over the north Atlantic, drifts slowly past the British Isles and Norway, far into the Arctic Ocean. This inflow of water into the Arctic is compensated by a strong outflow along the east coast of Greenland. This current rounds Cape Farewell, sends a large eddy northward to occupy Baffin Bay, and finally, under the name of the Labrador current, fills the space between the coast of North America and the Gulf Stream as far south as Chesapeake Bay, where it disappears by subsidence and mixture with the warmer water.

In the south Atlantic the Equatorial current flows from the Gulf of Guinea westward to South America, where the sharp angle at Cape St. Roque splits it in two. The northern branch crosses the equator to join the northern circuit, but the southern branch follows the coast of South America nearly to its southern extremity. The water gradually turns eastward and, reënforced by the Antarctic drift, returns to the African coast and passes northward to the Equatorial, completing the circuit. The Equatorial Counter current in the Atlantic is pinched for want of room, but appears in the eastern part as the Guinea current.

In the Indian Ocean south of the equator the circuit is similar to that of the other oceans, from Australia to Africa, southward to the Antarctic drift and back to Australia.

The basin of the Indian Ocean north of the equator is small and obstructed by the peninsula of India. A circuit, however, exists, but with the peculiarity that in summer (May to October) the movement is in the regular direction, westward in mid-ocean and eastward along the Asiatic coast, and in winter (October to May) these directions are reversed.

Generalization. — As a general statement, it may be said that the equatorial waters flow westward until they strike the edge of the continental block, where they turn poleward, recross the oceans in middle latitudes, and, returning toward the equator, complete the circuit. The principal movement of the water forms a great eddy on each side of the equator, turning in the northern hemisphere in the same direction as the hands of a clock (clockwise), in the

southern hemisphere in the opposite direction (counter-clockwise). In the north Pacific the principal eddy throws off a smaller reverse eddy along the Alaskan coast. In the north Atlantic the Gulf Stream drift into the Arctic and the return by the Greenland-Labrador current form a reverse eddy as large and important as the primary one. In the Pacific and Atlantic Counter currents form small reverse eddies between the Equatorials. In the southern hemisphere the open water permits an Antarctic drift, 600 to 1000 miles wide, to encircle the globe, into which the southern extremity of each continent projects and intercepts a portion of the stream.

Fig. 248.

Cause of Currents. — It is well known that the wind blowing steadily for a considerable time is able to start surface currents in the same direction. This is demonstrated in the currents of the Great Lakes, where there are no differ-

ences of temperature or saltness. It is also demonstrated by the currents of the Indian Ocean north of the equator, where the currents reverse their direction twice a year about one month after a similar change in the monsoon winds. It has been calculated that the force of the trade winds is sufficient in 100,000 years to set water in motion to the depth of 12,000 feet. If the map of the ocean currents, pp. 256, 257, is compared with the map of the prevailing winds, p. 305, the correspondence is at once evident. The equatorial currents have the same position and direc-

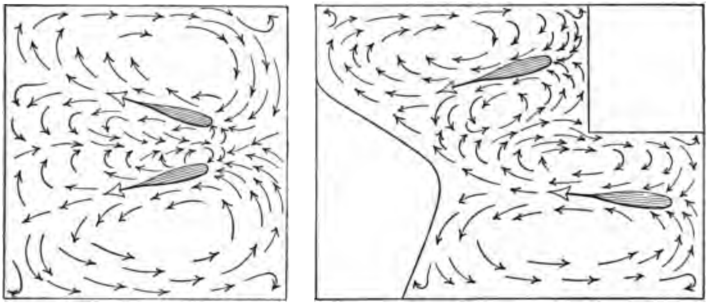


Fig. 249. Fig. 250.
Currents in pans of water, set up by blasts of air.

tion as the trade winds, the eastward-flowing currents are in the same latitudes as the prevailing westerly winds, and the centers of the great oceanic eddies are coincident with the tropic calms, while the counter currents flow eastward in the belt of equatorial calms. The Gulf Stream - Greenland eddy follows the same course as the southwesterly and northeasterly winds which circulate around a center south of Greenland. The correspondence is so nearly complete as to warrant the conclusion that the principal cause of the surface currents is the prevailing winds.

Realistic Exercise. — Sprinkle sawdust upon the surface of a pan or tank of water, and with a bellows, foot blower, or the mouth, blow

through a tube a current of air parallel with the surface of the water. At the place where the air current strikes the water there will be a slight depression of the surface, the water will flow in toward it from both sides, and a current will be set up which will move to the farther side of the pan, parallel with the blast of air, and returning will form a complete circuit on each side.

An Englishman, Mr. Clayden, has made and exhibited a model of the Atlantic Ocean, over the water of which blasts of air are blown in the place and direction of the prevailing winds. The result is a reproduction of the actual surface circulation, not only in its main features, but even in details like the turn of the Greenland current around Cape Farewell and the Baffin Bay eddy.

It has been maintained that differences of temperature and saltness might be causes of ocean currents, and it is probable that they do exercise some influence upon the movement, but it is impossible to determine just what that influence is. They play a subordinate part, and their effects are masked and overcome by other forces. As accurate knowledge of the sea increases, it becomes more and more evident that the happy guess made by Benjamin Franklin more than a century ago is the true explanation, and that nearly every detail of the circulation of surface waters in the sea may be satisfactorily accounted for by the force of the winds and the effect of land barriers.

Effects of Ocean Currents. — Surface currents carry their own temperature into the regions which they penetrate, and, by imparting it to the air above, modify the climate of neighboring land masses over which this air moves. Between the tropics the western part of each ocean is flooded with water which has made a long journey under a nearly vertical sun and has become heated to a high temperature; hence the belt of water above 70° F. is widest and deepest along the eastern coasts of the continents. The east sides of the oceans in the same latitudes are supplied with water

by currents coming from higher latitudes and also by water which rises from below in place of the water blown away by the trade winds; hence the west coasts of the continents are washed by water of comparatively low temperature. This contrast is plainly seen on the opposite sides of Africa and South America (see map, p. 253).

In middle and high latitudes of the northern hemisphere, west coasts are washed by warm currents and east coasts by cold currents.

The most extreme case of this kind is presented by the north Atlantic, where on the east side the isotherms are carried far northward by the Gulf Stream, and on the west side far southward by the Labrador current (see map, p. 253). Thus the ocean currents coöperate with the prevailing winds to make northwestern Europe habitable and to keep its harbors free from ice almost to the Arctic Circle, while Greenland and Labrador in the same latitude are ice-bound, snow-covered, and desolate. The same contrast exists in a less degree on opposite sides of the north Pacific.

Sea Ice.—The freezing point of sea water varies with its saltness from 32° to 26°. In the Arctic Ocean the ice forms every winter to a thickness of ten or fifteen feet. The *floe* or *pack* thus formed is broken up by tides and storms, and driven about by winds and currents. The pieces are forced against one another and the shore, and piled up in extreme confusion. The surface becomes so rough that it is almost impossible to travel over it. Lieutenant Markham's party north of Greenland was able to accomplish only seventy miles in forty days. Nansen's ship, the *Fram*, was able to make way through the ice by blasting it with dynamite. The largest masses are called *floebergs*. The shores of Greenland are crowded with both floebergs and icebergs (Fig. 86) derived from the glacial tongues of the ice cap (see p. 120). Both the sea and the land ice are carried far southward by the Labra-

dor current, and the largest bergs finally melt in the Gulf Stream. In the winter of 1872–1873 a part of the crew of the ship *Polaris* drifted on an ice floe from the north of Baffin Bay to the coast of southern Labrador, nearly 2000 miles, in six and a half months.

A still larger quantity of ice is supplied by the Antarctic ice cap, from which bergs 200 to 500 feet above water and sometimes several miles in length are continually being discharged. The Antarctic bergs are flat-topped and steep-sided (Fig. 87), and exhibit a stratified structure of alternate blue and white layers, which probably represent the snow-fall of successive summers and winters. As only

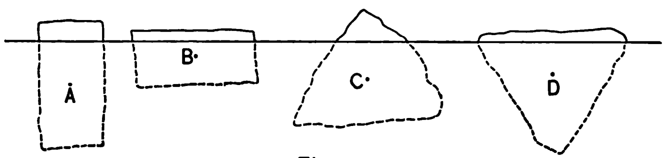


Fig. 251.

about one tenth of the mass of ice stands above water, the total thickness of these bergs must be from 2000 to 5000 feet.

As the form of an iceberg changes by irregular melting, it may turn over several times, always assuming a position in which *its center of gravity is as high as possible.* A berg having the form *A* (Fig. 251), unless weighted at the bottom, would take the position *B*, and *C* would turn upside down like *D*. Icebergs often transport considerable quantities of stones and dirt which have fallen from shore cliffs or have been dragged from the land. As the ice melts, these are distributed over the sea bottom far from their place of origin.

The Sea and Man. — The sea is the original source of the moisture in the air. The vapor, borne by the winds

over the land, falls as rain, supplying water for the use of plants and animals, and the flow of streams. The most productive lands are those which are near the sea or are accessible by winds from the sea.

The sea teems with living forms, many species of which, like the codfish, mackerel, herring, and oyster, form staple articles of food. The whale furnishes oil and the fur seal furnishes fur, both of such value that these animals have been nearly exterminated. From the sea are obtained sponges, corals, and pearls of great commercial value.

Large numbers of people seek the sea for health and pleasure. A sea voyage is a favorite method of travel, and the most popular resorts are those which afford sea air and sea bathing.

The sea was once regarded with dread and terror as being dangerous and destructive. It is often thought of as a barren, unproductive "waste of waters." To many peoples it has been an impassable barrier to migration. At first men crept timidly in small boats along the shore; but gradually they gained courage to venture out of sight of land and, guided by the stars, to find their way across the waters to distant countries. The most progressive peoples now use the sea as a means of communication and trade. Large vessels traverse it in all directions, carrying the products of every land to every other land. Civilized man has changed the sea from a barrier to a broad, easy highway of commerce. Many of the great cities of the world are great because they are seaports. The most prosperous and enlightened countries have a long seacoast. Russia loses no opportunity to secure ports upon the Pacific and Atlantic, and Great Britain has gained her high place among nations through her control of the sea.

BOOK IV. THE ATMOSPHERE

CHAPTER XXII

THE AIR

Composition. — The atmosphere, or gaseous portion of the earth, forms a complete spheroidal shell which surrounds the solid and liquid globe, and not only rests upon the surface of land and sea, but also penetrates them to a great depth. Its thickness, which is not definitely known, is certainly several hundred miles and may be many thousand. Its bulk is almost entirely made up of five gases, which are present in the proportions given in the following table: —

COMPOSITION OF THE AIR

NAME	PER CENT OF VOLUME	DENSITY
Nitrogen	76.95	.971
Oxygen	20.61	1.105
Water vapor (average)	1.40	.624
Argon	1.00	1.380
Carbon dioxide (average)	0.03	1.529
Air	99.99	1.000

These gases are not united or combined in any way, but are almost entirely independent of one another. They act like five separate and distinct atmospheres occupying the same space at the same time. The space which each gas occupies is determined by the balance between its own

expansive force, tending to make it expand indefinitely, and gravitation, which holds it down to the earth. Carbon dioxide, being the heaviest of all these gases, does not extend so far upward as the others. Oxygen is a little heavier than nitrogen, and its relative proportion decreases slightly in the upper air. Water vapor is the lightest of all, but its existence as vapor is so far dependent upon a warm temperature that it is almost absent at great heights.

Properties and Functions. — *Oxygen* combines freely with nearly all the elements, and in its numerous compounds forms about one half of the whole weight of the globe. By the process of respiration it supports the life of all plants and animals, and it is the universal agent of combustion. By respiration, combustion, decay, and other processes of oxidation the quantity of oxygen in the air is being continually diminished. This loss is partly compensated by the oxygen set free from plants in the process of food manufacture.

Nitrogen is extremely inert and enters into combination with other elements with difficulty. To it is due nearly three fourths of the pressure and density of the air. Without it birds could not fly, clouds and smoke would settle to the ground, and the force of the wind would be proportionately diminished.

Argon resembles nitrogen, with which it was confounded until near the end of the nineteenth century.

Carbon dioxide (CO_2), or carbonic acid gas, is a compound of carbon and oxygen formed in the active growing parts of plants and in the tissues of all animals and given off by them in the process of respiration. It is also produced by the combustion of all the ordinary forms of fuel, and sometimes escapes in large quantities from active vol-

canoes, old volcanic regions, and from many mineral springs. It forms the chief food supply of plants. The green parts of plants in the sunlight absorb carbon dioxide, separate it into its elements, retain the carbon, and give off the oxygen. Carbon dioxide plays an active part in rock formation, entering into combination with lime and other bases to form limestones. It also enters largely into the composition of the bones and shells of animals. While the absolute quantity of carbon dioxide is the least of all the principal constituents of the air, the part it plays in the economy of nature is second to none.

Water vapor is supplied by evaporation from all damp surfaces, but chiefly from the sea. When cooled it condenses again into water and falls as rain and snow. The quantity present in the air at different times and places is very variable, amounting sometimes to three per cent.

Visibility of Air.—The air is sometimes visible. When thrown into agitation by heat it may be seen rising from a stove or from the heated ground. Under proper conditions of illumination and background the wind may be seen as plainly as a current of water.

Weight and Pressure.— At sea level a cubic foot of air weighs about one ounce and a quarter, and the weight of all the air above sea level produces an average pressure of 14.74 pounds upon every square inch of surface. This pressure is equal in all directions, — downwards, upwards, or sidewise at any angle. The pressure of the air is measured by the *barometer*.

Fig. 252. – Simple forms of barometers.

If a glass tube about 32 inches long is filled with mercury, inverted, and the open end inserted into a cup

of mercury, the mercury in the tube will fall until only enough remains to balance the weight of a column of air of the same size extending to the top of the atmosphere. Such an arrangement is essentially a mercurial barometer. We can not weigh the column of air directly, but we can weigh the column of mercury which balances it. The height of such a column at sea level averages about 30 inches, and, if one square inch in area of cross section, weighs 14.74 pounds. If the barometer is carried to higher elevations, there will be less air above it, and the mercury will fall. If the pressure of the air increases, it will drive more mercury into the tube. The pressure of the air is measured and expressed in terms of the height of the column of mercury which it supports. When the air pressure is said to be 29.50 inches, it means that the air pressure is sufficient to support a column of mercury 29.50 inches high. A description of the standard barometer and instructions for its use are given in the Appendix, pp. 400, 401.

Density. — The air being easily compressed, its density is proportional to the pressure to which it is subjected, and consequently diminishes as the height above the sea increases. Density and pressure are also influenced by other conditions, of which temperature and humidity, or quantity of water vapor it contains, are the most important. When air is heated it expands and becomes less dense. The same effect is produced by the addition of water vapor. On warm, damp days the pressure and density are less, and the barometer stands lower than on cold, dry days.

Temperature. — The temperature of the air is determined by the amount of heat received and absorbed from the sun and earth. As the sun heat passes through the air on its way to the earth, about one third of it is absorbed by the air and goes to raise its temperature, while the remaining two thirds reaches the surface of the land and water. A part of this is reflected back without warming the earth and another part, being absorbed, goes to raise or maintain the temperature of the land and water. The

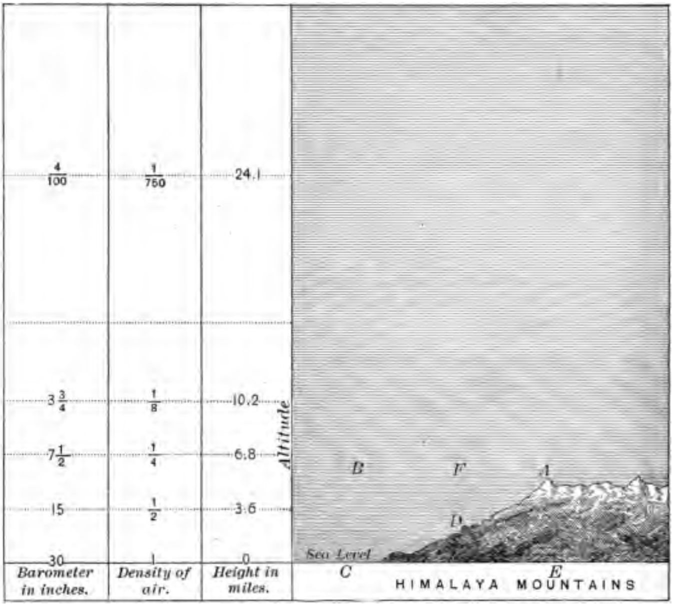


Fig. 253.—Decrease of density and amount of air with increase of altitude.

warm earth in turn warms the air next to it slightly by conduction and still more by radiating its heat upward.

Of the heat reflected and radiated from the earth about 60 per cent is absorbed by the air and goes to raise its temperature still further. The heated air radiates some of its heat back to the earth, and so a continual exchange of heat is going on between the air and the earth; but on the whole and in the long run as much heat escapes from the earth as it receives. The air takes toll as the heat passes through it both ways, coming and going, and temporarily retains about 70 per cent of the whole amount supplied from the sun.

The lower air absorbs much more heat than the upper air, and consequently is maintained at a higher temperature. This is due largely to the presence of cloud, fog, dust, and smoke, which may be regarded as atmospheric

sediment held in suspension somewhat as fine mud is suspended in water. The larger proportions of carbon dioxide and water vapor in the lower air also increase its absorptive power for heat.

If the air were perfectly clear, dry, and free from carbon dioxide, the heat of the sun would reach the earth with slight obstruction, and in the daytime the land would become excessively heated. In the night the heat would escape with equal rapidity, and the land would become excessively cooled. Upon lofty mountains which reach up through the zone of dust, cloud, and water vapor this is the actual condition. The clouds act as a blanket to protect the earth from the fierce heat of the sun by day and to prevent the escape of heat at night, thus maintaining a more equable temperature.

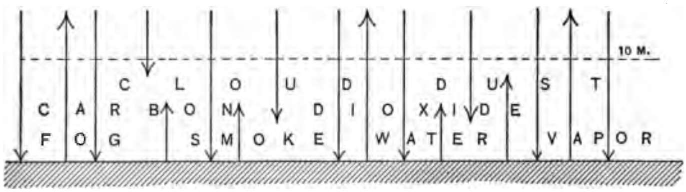


Fig. 254.

In Fig. 254 the horizontal line at the bottom represents the surface of the land or water, and the dotted line indicates an elevation of ten miles. The total heat received from the sun is represented by ten arrows, of which three are stopped by the air, and seven reach the earth. The seven arrows pointing upward represent the heat given off from the earth, of which four are stopped by the air and three pass directly through into space.

The temperature of the air diminishes on an average one degree for every 300 feet of elevation. The average temperature of the air also diminishes from the equator to the poles at the rate of about one degree for every degree of latitude; this is due chiefly to the spheroidal form of the earth, which causes the sun's rays to strike more obliquely and to be distributed over more space toward the poles (see p. 22). The distribution of temperature in the atmosphere is subject to these two general laws, but is made quite irregular by various influences, which will be discussed later.

The Measurement of Temperature. — Temperature is measured by the thermometer, several varieties of which are described in the Appendix (pp. 398, 399).

Weather Observations.— Every student should provide himself with the best thermometer he can afford. Its error may be determined by comparison with a standard thermometer in the laboratory. Comparisons should be made at two or more temperatures, one at or below freezing, and one near 100°. The thermometer should be placed in a suitable position at home. The north side of a post at some distance from any building, and four feet from the ground, will answer the purpose. At two periods every day, morning and evening, as between 7 and 8 A.M., and between 7 and 8 P.M., let the student read and record the temperature, observing and recording at the same time the direction of the wind as shown by a vane placed above trees and buildings; the state of the sky as to clearness or cloudiness; the fall of rain or snow, and any other notable phenomenon of the weather, as fog, hail, frost, etc. These observations should be continued for at least three months, and, if possible, for a year. The record may be kept in the following form:—

DATE	HOUR	TEMP.	WIND AND SKY	REMARKS

The direction of the wind may be indicated by an arrow flying with the wind as on a weather map, the state of the sky by an open or shaded circle, attached to the arrow; means a northwest wind with clear sky; an east wind with sky half cloudy; a south wind with sky overcast.

CHAPTER XXIII

MOISTURE IN THE AIR

Evaporation. — Under suitable conditions, evaporation takes place from all damp surfaces and the water vapor mingles with the surrounding air. The heat in the water makes the molecules vibrate and some of those at the surface fly off into space. Ice evaporates as well as water, but the higher the temperature, the more rapid is the evaporation, and at boiling point molecules escape from all parts of the water, forming bubbles of steam. At the moment of evaporation, water expands to about 1700 times its liquid volume and is transformed into an invisible gas or vapor. The quantity of vapor which can exist in any given space depends upon the temperature of the vapor. When the space contains all it can hold, the vapor is said to be *saturated.*

Grains of Saturated Water Vapor in a Cubic Foot at Various Temperatures

10°	.776	34°	2.279	58°	5.370	82°	11.626
12°	.856	36°	2.457	60°	5.745	84°	12.356
14°	.941	38°	2.646	62°	6.142	86°	13.127
16°	1.032	40°	2.849	64°	6.563	88°	13.937
18°	1.128	42°	3.064	66°	7.009	90°	14.790
20°	1.235	44°	3.294	68°	7.480	92°	15.689
22°	1.355	46°	3.539	70°	7.980	94°	16.634
24°	1.483	48°	3.800	72°	8.508	96°	17.626
26°	1.623	50°	4.076	74°	9.066	98°	18.671
28°	1.773	52°	4.372	76°	9.655	100°	19.766
30°	1.935	54°	4.685	78°	10.277	102°	20.917
32°	2.113	56°	5.016	80°	10.934	104°	22.125

The quantities given in the table on p. 280 are the same whether the space is a vacuum or is already filled with air or other gases. The air has nothing to do with evaporation except to retard it. Water evaporates more rapidly into an absolutely empty space than into dry air, but at a given temperature the same quantity will evaporate into each. When water vapor is added to air, the expansive power of the mixture is increased, the surrounding drier air is pushed away, and the whole mass of moist air expands until its density becomes less than that of the drier air. If a cubic foot of dry air at a temperature of 80° and weighing 516 grains rests upon a body of water and evaporation takes place until 11 grains of water vapor is added, the whole mass of the mixture will weigh 527 grains, but a cubic foot of it will weigh only 510 grains, and will be less dense than the original dry air.

Humidity.— The quantity of water vapor actually present in space or air is called its *absolute humidity*. The quantity which the space might contain if full or saturated is called its *capacity*. The ratio of the absolute humidity to the capacity is called the *relative humidity*.

If an eight-ounce bottle contains two ounces of water, its absolute humidity may be said to be two ounces, its capacity eight ounces, and its relative humidity two eighths or 25 per cent.

Absolute humidity answers the question, how much is there in it? capacity answers the question, how much will it hold? relative humidity answers the question, how full is it? If the relative humidity of air is above 80 per cent, it may be said to be damp air; if below 50 per cent, dry air. Whether air is dry or damp depends not only upon the quantity of moisture which it contains, but also upon its capacity as determined by temperature. Air at 32° containing two grains of water vapor to the cubic foot is very damp because nearly saturated. If heated to 70°, it would still contain two grains, but would be very dry because only one fourth saturated. On the other hand, dry air may become damp by cooling without the addition of any moisture.

Realistic Exercise. — Fill a bright tin cup half full of water at the temperature of the room, add a few lumps of ice, and stir the mixture with a thermometer. Watch carefully the outer surface of the cup and at the moment it becomes dulled by the formation of dew, read the thermometer. The vapor in contact with the cup has been cooled to saturation and has begun to condense. The temperature at which this

occurs is called the *dew-point*. Since vapor at the dew-point is saturated, *absolute humidity at dew-point equals capacity.* By reference to the table on p. 280 the absolute humidity may be found. Suppose the dew-point to be 40°, then the absolute humidity or actual quantity of vapor present is 2.849 grains per cubic foot. If the temperature of the room is 70°, its capacity according to the table is 7.980 grains per cubic foot, and its relative humidity is 2.849 ÷ 7.980, or 35.7 per cent.

Hygrometer. — A more convenient method of measuring relative humidity is by means of the hygrometer (see Appendix, pp. 401, 402).

Condensation. — When water vapor is cooled below the point of saturation, condensation takes place and the vapor changes to fog, cloud, rain, snow, hail, dew, or frost. Cooling in the atmosphere is brought about by several processes.

(1) **Expansion.** — Wherever air rises and reaches successive levels of less pressure, it expands and some of its heat energy is expended in pushing away the surrounding air. Thus without any transfer of heat to other bodies, it is cooled simply by its own expansion one degree for every 183 feet of ascent.

This is called *mechanical* cooling and is one of the most efficient causes of condensation. Air at 70° F. and of 50 per cent relative humidity would become saturated by a rise of 4000 feet. As soon as condensation begins, the latent heat of the water vapor is liberated and the cooling by expansion is retarded. Descending air is warmed by compression one degree for every 183 feet of descent.

(2) **Radiation.** — Air is cooled by radiating its heat to cooler objects in the vicinity, as the ground, the sea, a mass of ice or snow, or a body of cooler air. This cause is most efficient in currents of air moving in any direction from warmer to cooler regions.

(3) **Conduction.** — When air comes in actual contact with a cooler body, it loses some of its heat by conduction. This process is comparatively unimportant because air is a poor conductor of heat, and only a thin layer of it next to the cooler body is affected.

(4) **Mixture.** — Air is often cooled by mixture with cooler air. This is not a different and distinct process, but furnishes favorable conditions for rapid radiation and conduction.

Clouds. — The condensation of water vapor in the air near the earth produces fog; at higher altitudes, cloud.

Clouds are composed of minute particles of liquid water or of ice, a sort of water dust. Unless borne up by a rising current, they settle slowly through the air, but on reaching a stratum of unsaturated air again evaporate. Generally condensation continues above and thus the cloud persists, although continually destroyed and renewed. When vapor is carried horizontally forward by an air current, it may condense at one place and evaporate farther on: thus the cloud appears to be moving forward, but does not extend beyond a certain point.

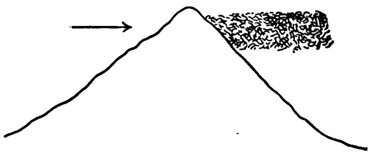


Fig. 255.

This process is strikingly shown by the "banner cloud" which sometimes hangs for hours from a mountain peak, like a flag attached to a staff. A current of saturated air chilled by the mountain condenses on the leeward side and evaporates at some distance beyond. This cloud is a temporary form assumed by the vapor as it passes through a certain space. The ever changing forms of clouds are largely due to evaporation and renewal.

Fig. 256. — Cumulus.

Cloud Forms. — All the numerous cloud forms may be classed under four principal types: —

(1) *Cumulus* clouds are rounded masses like heaps of wool, generally formed at the top of an ascending column of air. Their horizontal base marks the level where saturation is reached, and above this condensation may continue until the cloud is piled up to the height of five miles or more. Cumulus clouds are characteristic of the equatorial regions and of warm summer afternoons elsewhere when the columns of air started upward by the heat of the sun have reached a considerable height. They often result in showers and thunderstorms.

Fig. 257. — Cirrus.

(2) *Cirrus* clouds are light and feathery, resembling ostrich plumes, dabs of thin white paint, loose wisps of straw, a cat's tail, and various fantastic forms. They are formed at heights of five or more miles and consist of minute ice crystals or snowflakes.

(3) *Stratus* clouds extend in long, horizontal bands or layers and vary in height from 1000 feet to three miles.

Fig. 258. — Stratus.

(4) *Nimbus* clouds are those from which snow or rain is falling. They may be formed from stratus or cumulus clouds.

Many combinations and intermediate forms occur, of which cirro-stratus, cirro-cumulus, and strato-cumulus are the most common.

Fig. 259. — Nimbus.

Precipitation. When water vapor condenses into particles so large that the air

can no longer support or evaporate them, a falling or precipitation occurs in the form of rain, snow, or hail. As the particles fall through saturated air, condensation continues, and the drops grow larger up to a certain limit of size, when they break into smaller drops. If the condensation occurs at a temperature below freezing, the vapor crystallizes into snowflakes. Of these there are numerous forms, but all agree in having angles of 60° between their branches and in being six-pointed or six-sided. Snow or rain may evaporate before reaching the earth.

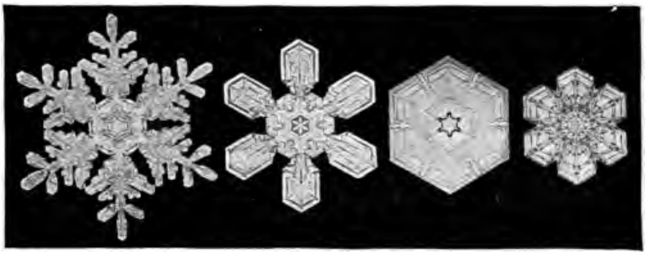


Fig. 260. — Snow crystals, magnified.

Hailstones are masses of ice, or of ice and snow, which are sometimes as large as hens' eggs or even larger. Their structure is often complicated by alternate layers of snow and ice, showing that they have passed through a variety of atmospheric conditions. The exact method of their formation is not well understood.

Measurement of Precipitation. — Rainfall is caught in a metal cylinder called a *rain gauge*, and its depth is measured in inches (see Appendix, p. 402). Snowfall is determined by melting the snow in the gauge and measuring the depth of water produced. On an average ten inches of snow makes one inch of water, but the proportion is very variable.

Dew and Frost. — When the temperature of any surface falls below the dew-point of the surrounding air, water

vapor begins to condense upon it in the form of *dew*. If the temperature of the surface is below freezing, the vapor crystallizes directly into *hoarfrost*.

The dew does not fall, but is formed at the place where it appears. Frost is not frozen dew any more than snow is frozen rain. Much of the vapor which goes to form dew escapes from the ground or is given off from the surface of growing plants. Dew is heavier on a clear night because the heat is then radiated from the earth more rapidly than on a cloudy night. A tree, board, piece of paper, or cover of any kind acts like cloud and may keep the air beneath from cooling to dew-point. The under side of a board or stone next to the ground may be covered with a heavy dew while the upper side remains dry. This is due to the rise of vapor from the ground. Dew is heavier upon grass than upon bare ground, because of the excess of vapor given off from the grass, and because grass is a better radiator than earth. Dew is heavier in a valley than upon a hill top, because there is more moisture in the ground there to evaporate, and because the cooler and heavier air settles down into the valleys and lifts the warmer air out. A breeze prevents the formation of dew by keeping the air near the ground stirred up and mixed with the drier and warmer air above. The conditions favorable or unfavorable for the formation of dew and frost are often very delicately adjusted, and a slight difference in elevation, exposure, or condition of the surface will determine whether dew or frost will occur or not.

CHAPTER XXIV

WINDS

Atmospheric Convection. — When air is heated or made more damp by addition of water vapor, it expands and becomes less dense than the surrounding air, which crowds in from all sides and buoys the lighter air upward. The draught in a stove or lamp is a familiar example of the rise of light air, and the smoke from a fire burning in the open air shows that there is an upward current in this case also. Careful observation will discover the movement of the cool air toward the fire. If there is no wind stirring, the rising column of smoke may be seen to spread out horizontally when it reaches a stratum of air of its own density. A downward movement at some distance from the fire takes place, but is too slow to be easily detected.

Every wind that blows is a part of some convection circuit, which may be hundreds or thousands of miles in extent. The air is set in motion and the movement is kept up by a difference in the atmospheric pressures over different parts of the earth's surface. The upward and downward currents of the circuit are usually beyond the reach of ordinary observation, and in the regions where they leave or reach the surface of the earth the air is apparently calm. The lower horizontal currents constitute the commonly observed winds, but somewhere in the upper air there is always a current in a nearly opposite direction, which is sometimes made perceptible by the movement of clouds.

Pressure and Winds. — The direction and force of the winds are always dependent upon differences of atmospheric pressure and can be explained as the result of the distribution of pressure. The location of regions of high and low pressure are shown on a map by the use of *isobars* or lines drawn through places of equal pressure.

Figure 261 shows the isobars of the eastern part of the United States for the morning of March 26, 1898. The figures attached to each line show the height of the barometer along that line. The highest pressure was 30.8 inches in New England and the lowest 29.9 inches in Wisconsin, the difference being 0.9 inches. If a barometer could have been carried very rapidly westward along the line *AB*, it would have fallen at the rate of one tenth of an inch for every 100 miles. The rate of change of pressure along any line crossing the isobars is called the *barometric gradient* or *pressure slope*. It is evident that the rate of change of pressure is greatest, or, in other words, the slope is steepest, along a line which crosses the isobars at right angles, and that where the isobars are close together the slope is steeper than where they are far apart. Gravitation tends to make the air move by its own weight down the steepest slope from high to low pressure. The arrows on the map fly with the wind and show that the wind was moving down the slope along lines parallel to *CB*, and not in the direction of the steepest slope *AB*. The cause of this slant in the direction of air movement

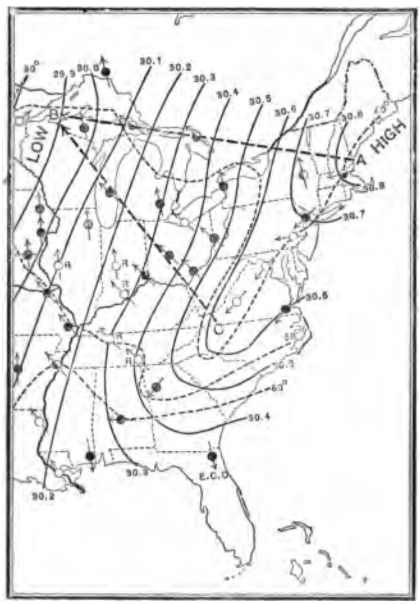


Fig. 261.

(——— Isobars. - - - - - - Isotherms.)

will be explained on pp. 290–292. In Fig. 262 the directions of slope *AB* and of the wind *AC* are opposite to those in Fig. 261. The isobars are farther apart, showing that the slope is less steep (one tenth of an inch to 150 miles), and the wind has a smaller velocity.

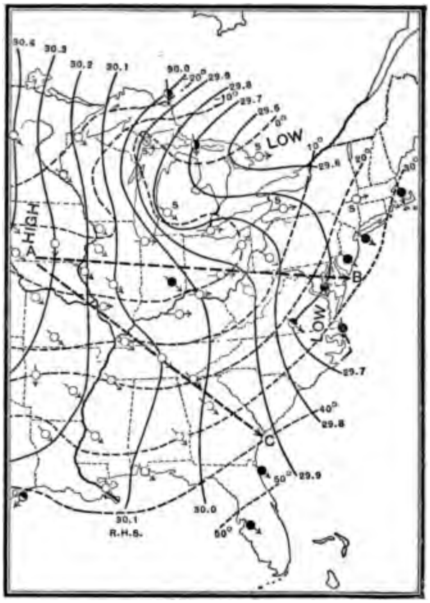


Fig. 262.

These examples illustrate the first law of winds: *By the force of gravitation winds always blow from a region of high pressure to a region of low pressure with a velocity which varies with the steepness of the pressure slope.*

Velocity of the Wind. — The average wind velocities in the United States vary at different localities between four and fourteen miles per hour. The velocity is greater over the sea than over the land and increases very rapidly with altitude for a few hundred feet and then more slowly. Velocities of 200 miles per hour have been observed at high altitudes and in tornadoes on the surface of the land. (See Appendix, p. 404.)

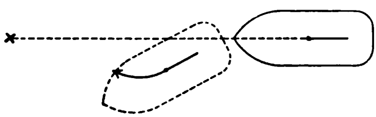


Fig. 263.

Effect of Rotation of the Earth. — If a person is walking upon the deck of a moving steamer toward some fixed object upon the shore ahead of the ship, and the pilot turns the steamer to the left while the walker continues in the same direction as before, his course will be deflected toward the right-hand

side of the steamer and he will describe upon the deck a curved path leading to the right-hand side. The same effect is noticed in walking through a car while it is running around a curve. The walker tends to move straight on and is thrown against the seats on one side of the car. The rotation of the earth tends to produce a similar effect upon all moving bodies. If a globe is viewed from a point directly above the north pole while it is rotated from west to east, the northern hemisphere will be seen turning counterclockwise about the pole as a center. Every north-south line is constantly changing its direction in space. The same is true of any portion of an east-west line.

These facts are shown upon the map, Fig. 264. Each meridian, as *A*, is carried by the rotation of the earth to new positions *B*, *C*, *D*, etc.

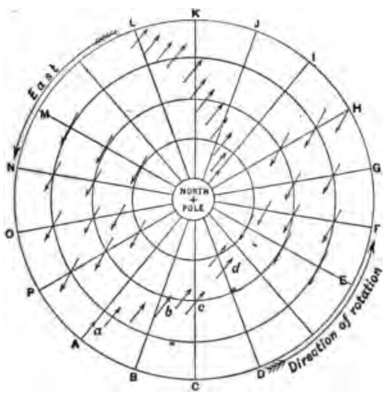


Fig. 264.

If an arrow starting northward on *A* continues in the same direction, when carried around to *C* it will be moving northeastward. An arrow starting westward on *E*, when carried to *H* will be moving northwestward. An arrow starting southward on *I*, when carried to *K* will be moving southwestward. An arrow starting eastward on *M*, when carried to *P* will be moving southeastward. At all points on a rotating earth, except at the equator, directions are continually changing so that if any moving body could maintain absolutely its original direction it would move toward all points of the compass in the course of one rotation. On account of friction no moving body can maintain absolutely its original direction, yet it is deflected by rotation more or less rapidly with a force which increases from the equator to the poles. The deflection is to the right in the northern hemisphere and to the left in the southern. This is known as *Ferrel's Law*.

Figure 265 shows the path of a body starting northward from any point O in the northern hemisphere and *moving without friction*. As it reaches higher latitudes, the deflection is more rapid and it turns to the east and south. As it returns toward the equator the deflection is less rapid toward the west, and it would thus describe a series of loops around the earth toward the west, between the parallels M and N. The form and limits of the loops would vary with the latitude and the speed.

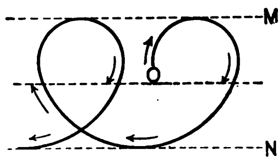


Fig. 265.

Realistic Exercise. — The subject of deflection by the rotation of the earth is a difficult one to explain and to understand, and has been erroneously stated in many text-books. The deflection is not a lagging behind or running ahead due to increasing or lessening speed of rotation. Perhaps the simplest illustration of the deflective effect of rotation may be made as follows: On a sheet of pasteboard draw two straight lines crossing at the center at right angles, and mark the ends of the lines north, south, east, and west. Lay the sheet on the table in such a position that the south-to-north line extends from the observer toward some fixed object beyond. Start a pencil along the line toward the north, and while the sheet is rotated counterclockwise, keep the pencil moving toward the fixed object. The line made by the moving pencil will curve away from the straight line to the right or to the east of *north on the sheet*. If the pencil is started east along the west-to-east line, the result will be a curve to the south of east. The pencil does not change its direction in space, but as the sheet rotates under it, its direction on the sheet continually changes, and always to the right of its course at any given moment, as in the northern hemisphere. If the sheet is rotated clockwise, the lines will curve to the left, as in the southern hemisphere. The more rapid the motion of the pencil, the less sharp will be the curve; the more rapid the rotation, the more sharp the curve. A similar illustration may be made with chalk on

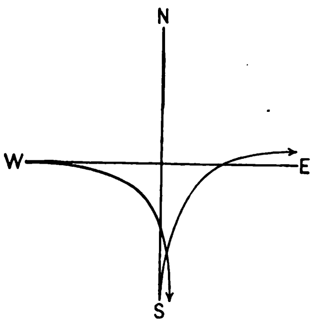


Fig. 266.

a black globe. An open umbrella mounted so as to turn upon its stick as an axis answers the purpose of a black globe.

The winds are probably deflected more than any other moving body by the earth's rotation, and from this arises the second law of the winds: *On account of the earth's rotation the path of the winds down a pressure slope in the northern hemisphere is to the right of a line perpendicular to the isobars, and in the southern hemisphere to the left.* (See Figs. 261, 262.) The angle at which the wind crosses the isobars increases with the latitude.

CHAPTER XXV

INSOLATION AND TEMPERATURE

The Distribution of Insolation. — The distribution of temperature, of pressure, of winds, and of rainfall over the face of the earth are so closely related that they can not be understood separately. They all depend primarily upon the distribution of the rays of the sun, or *insolation*, and this is determined chiefly by the form, attitude, and motions of the earth, as explained in Chapter I. On account of the spheroidal form of the earth there is but one ray of the sun that strikes its surface vertically, and the amount of insolation received decreases in every direction from the point which receives the vertical ray.

At the equinoxes, March 21 and September 23, the vertical ray strikes the equator, but at the winter solstice, December 22, the vertical ray strikes the Tropic of Capricorn, and at the summer solstice, June 21, it strikes the Tropic of Cancer. Thus the tropics bound a zone of maximum insolation which receives the vertical ray of the sun during some portion of the year. At the equinoxes the tangent rays reach to either pole, but at the solstices they strike the polar circles, 23½° beyond one pole and 23½° short of the other. Thus the polar circles bound areas of minimum insolation which receive the tangent rays of the sun at noon during some portion of the year. Between the tropics and polar circles are zones of medium insolation. The belts of equal insolation on any given day are bounded by parallels of latitude, but they swing back and forth, north and south, through the year, following the apparent daily path of the sun through the heavens.

During the year the sun shines an equal number of hours upon all parts of the earth's surface, but in the polar regions the insolation is nearly all received in the summer, while near the equator it is almost equally distributed through the year.

The general result is shown in Fig. 270 (at the left), which gives the

total insolation received in a year at different latitudes, expressed in percentages of that received at the equator. All places within the tropics receive more than 90 per cent as much insolation as the equator, while all places within the polar circles receive less than 50 per cent, the amount at the poles being about 42 per cent.

The Distribution of Temperature is shown upon a map by means of *isotherms* or lines of equal temperature. Figure 267 shows the mean annual temperature, and Figs. 268, 269, the mean temperatures of January and July, each being the coldest month in one hemisphere and the warmest in the other.

The isotherms are based upon millions of temperature observations made in all parts of the world. For the annual isotherms the average of the temperatures for all the days of the year in each area of one or two square degrees is calculated; for the monthly isotherms the average of all the temperatures recorded for the month. In these maps the effect of elevation is eliminated and all temperatures are reduced *to what they would be at sea level*, by adding a definite amount to the observed temperature. The observed mean annual temperature of Salt Lake City is 51.3°, its elevation above the sea is 4300 feet, 8.7° is added and the annual isotherm of 60° is drawn through it. Isotherms showing the actual temperature as affected by elevation would be too crooked and irregular to be shown upon a map of this scale. On the ordinary weather and temperature maps of a limited area, like the United States, the isotherms show the actual surface temperatures.

It is evident from the maps that the distribution of temperature is quite different from that of insolation. While the isotherms extend in a general east-west direction (why?) they are irregular in course and spacing. The irregularity is greater in the northern hemisphere than in the southern, and in January than in July.

Effect of Land and Water. — If the surface of the earth were all water or all land of uniform elevation, the isotherms would be parallels of latitude and the temperature would decrease regularly and equally along each meridian from the equator to the poles. In the winter the isotherms

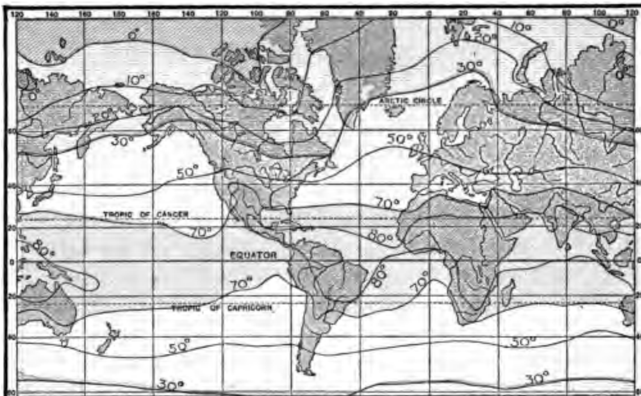


Fig. 267. - Isotherms for the year.

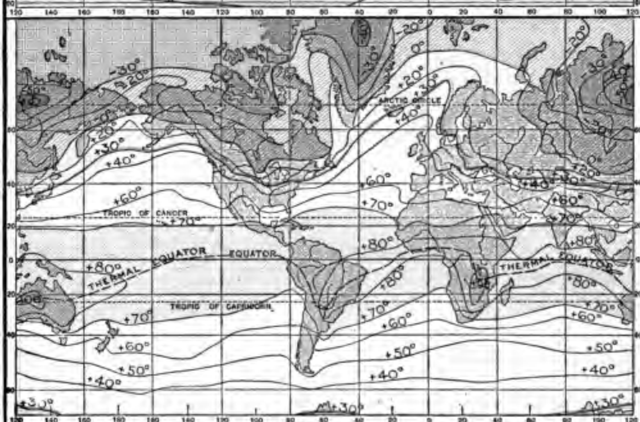


Fig. 268. - Isotherms for January.

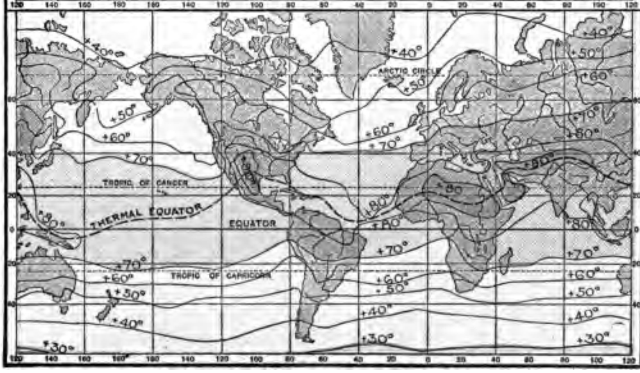


Fig. 269. - Isotherms for July.

bend toward the equator over the land, and away from the equator over the water, showing that the land is colder than the water. In the summer these conditions are reversed.

At least five causes combine to produce this result.

(1) **Difference in Capacity for Heat.** — It requires about twice as much heat to raise the temperature of a cubic foot of water one degree as it does to raise the temperature of an equal bulk of land. Hence from this cause alone a land surface receiving the same amount of insolation as an equal water surface is warmed twice as rapidly.

(2) **Difference in Penetrability for Heat.** — The sun's rays can not penetrate the land deeply, and as the land is a poor conductor of heat only a thin layer is warmed, while the rays penetrate the water to the depth of 600 feet, and the heat is distributed through a much larger volume of water than of land.

(3) **Difference in Mobility.** — The land is fixed while the water is movable. The water which is warmed often flows away and its place is taken by cooler water. Thus the heat received by the land is concentrated and that received by the water is diffused.

(4) **Difference in Evaporation.** — About one half the heat received by the water is expended in producing evaporation and does not raise the temperature of the water.

(5) **Difference in Cloudiness.** — Cloud and fog are more prevalent over the water than over the land, and these retard the heat on its way to and from the water.

In spring and summer the land is heated more rapidly than the water, and in autumn and winter, being a better radiator and having less heat to lose, it cools more rapidly. The rise and fall of temperature in the water is less than on the land and is retarded in time, reaching a maximum in the northern hemisphere in August, and a minimum in February. *The temperature of a land surface is subject to great variation, that of a water surface to small variation.*

Effect of Winds and Currents. — The irregularity of the isotherms is partly due to ocean currents and prevailing winds which carry their own temperature into regions which otherwise would be warmer or colder. The northward bend of

the isotherms on the west coasts of Africa and South America is due to the cold ocean currents from the Antarctic drift, and the southward bend on the east coasts is due to the warm equatorial currents. The great bend of the isotherms northward on the European side of the north Atlantic is due to the Gulf Stream and the southwest winds which accompany it, and the southward bend on the American side is due to the Labrador current.

Regions of Maximum and Minimum Temperature. — In January the regions of lowest temperature are in northeastern Asia and Greenland (why ?), and the regions of highest temperature in Australia and South Africa (why ?). In July the areas of low temperature are in the vicinity of the poles, and the areas of high temperature in North Africa, southwestern Asia, and southwestern North America (why ?). The lowest temperature ever recorded is – 96° in northeastern America, the highest shade temperature 154° in the Sahara. A line drawn through the points of highest temperature on each meridian is called the *thermal equator*. It swings north and south with the sun, but is much farther from the geographical equator in July than in January (why ?).

Zones of Temperature. — The tropics and polar circles do not divide the face of the earth into zones of temperature, but of insolation. The true temperature zones are bounded by isotherms. Any division of zones must be somewhat arbitrary, but the isotherms which mark the monthly averages of 30° and 70° are convenient boundaries. The torrid zone lies between the isotherms of 70° on each side of the equator, the temperate zones between those of 70° and 30°, and each frigid zone is inclosed by that of 30°.

If the position of each of these zones in January and July is observed on the maps, it will be seen that they all swing north and south with the sun. The change of position is greater in the northern hemisphere than in the southern. The torrid zone shifts about fifteen degrees in latitude and is widest in July, especially over Asia. In January the north temperate zone is narrow and irregular, but in July it widens so far as to crowd the north frigid zone out of existence.

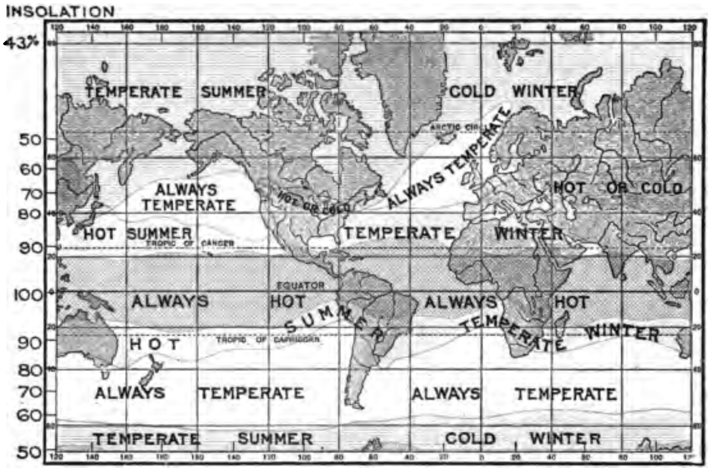
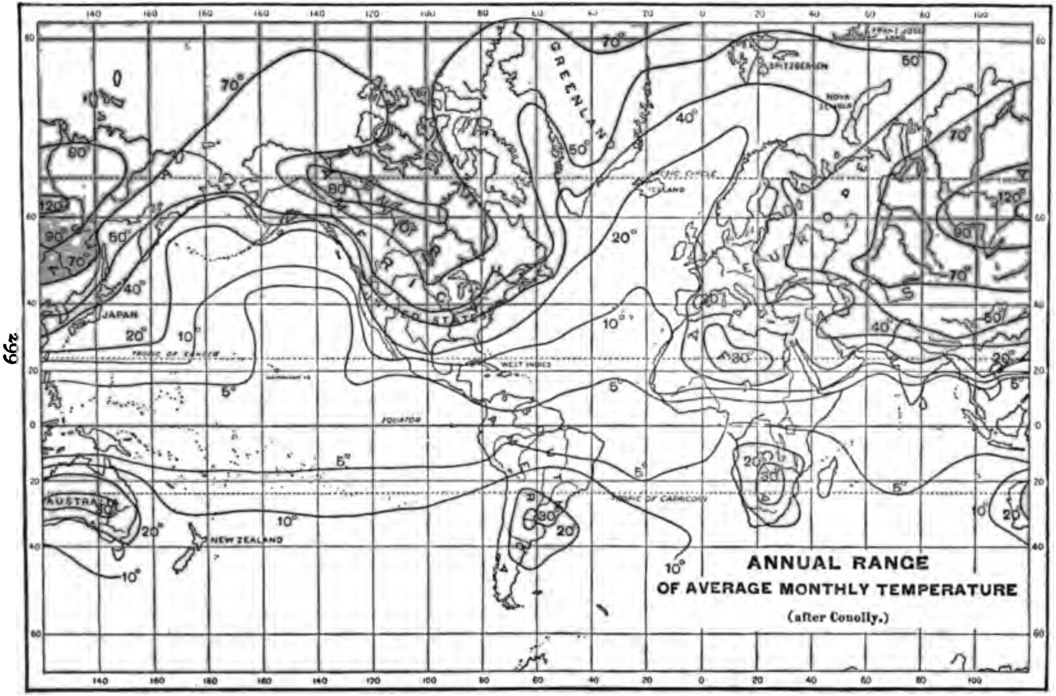


Fig. 270. — Temperature zones.
(Insolation in percentages at left.)

By drawing the isotherms of 70° and 30° for January and July upon one map, as in Fig. 270, we obtain a set of zones which are not shifting but fixed, and reveal in a striking manner the temperature conditions of the globe. Upon this map *hot* means an average temperature in the hottest month above 70°, *cold* an average temperature in the coldest month below 30°, and *temperate* an average monthly temperature between 70° and 30°. The space between the tropics is mostly occupied by a belt which is *always hot*, a truly torrid zone. This is bordered upon either side by a belt in which the summers are hot and the winters temperate. In the southern hemisphere there is a truly temperate zone in which both summer and winter are temperate. In the northern hemisphere this temperate zone is confined to the oceans. Over the land masses it is replaced by regions of exactly opposite conditions, a truly *intemperate* zone, in which the summers are hot and the winters cold. Beyond the temperate zones are belts of cold winters and temperate summers, and in the southern hemisphere only there is, around the pole, a truly frigid zone which is always cold.

Range of Temperature. — The difference between the lowest and the highest temperature at any given place is *called the range.* It may be reckoned between the high-



ANNUAL RANGE
OF AVERAGE MONTHLY TEMPERATURE
(after Conolly.)

est and lowest temperatures observed in twenty-four hours, which gives the *daily* range; between the average temperatures of July and January, which gives the *annual* range; between the absolutely highest temperature observed during the year and the absolutely lowest, which gives the *absolute annual* range; and in other ways.

The map, p. 299, shows that the average annual range increases with the latitude (why ?), and with distance from the sea (why ?), and is greater in the northern hemisphere than in the southern (why ?). The centers of maximum range nearly coincide with those of minimum temperature. The greatest absolute range is 182° at Verkhoyansk, Siberia.

Figures 271 and 272 show the influence of latitude and of land and water upon range of temperature.

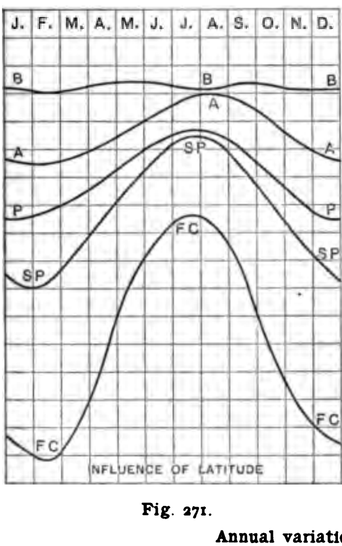


Fig. 271.

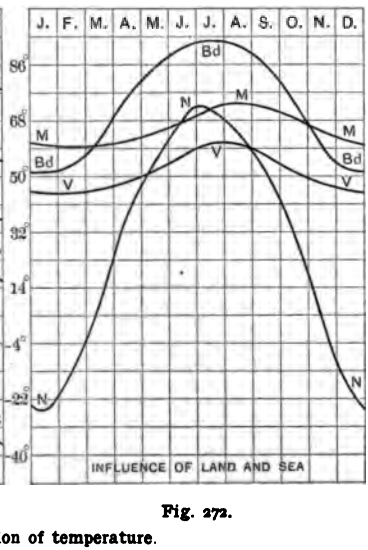


Fig. 272.

Annual variation of temperature.

B, Batavia	latitude 6° 8′ S		M, Madeira	latitude	32°38′ N
A, Algiers	" 36°47′ N		Bd, Bagdad	"	33°20′ N
P, Paris	" 48°50′ N		V, Valentia	"	51°55′ N
S P, St. Petersburg	" 59°56′ N		N, Nerchinsk	"	51°58′ N
F C, Fort Conger	" 81°44′ N				

CHAPTER XXVI

THE DISTRIBUTION OF PRESSURE AND WINDS

The Distribution of Pressure.— Isobaric maps may show the distribution of the average pressure for the year or month, or the actual pressure existing at a given day and hour. As on isothermal maps, the effect of altitude is eliminated, and all pressures *are reduced to sea level* by adding to the observed pressure the pressure of a column of air extending from sea level up to the height of the place of observation. The quantity to be added to the reading of the barometer varies with the temperature and density of the air at the time and place of observation, and furnishes a problem of unusual difficulty. The average addition is about one tenth of an inch for every 100 feet of elevation. (See p. 407.)

Figure 274 shows that the regions of high average annual pressure (above 30 inches) form two nearly continuous belts around the globe, situated near 30° south latitude and 40° north latitude. The northern belt is the more irregular and is widest over the land. In the equatorial and polar regions the pressure is low, or below 30 inches, the lowest so far as known being at about 60° south latitude.

Figure 275 shows that in January the northern belt of high pressure is expanded so that it covers the greater part of the land surface, but is interrupted by a large area of low pressure over the north Atlantic and Arctic oceans and Greenland and a smaller one over the north Pacific. The southern belt of high pressure is broken up into three centers which lie over the oceans. The highest pressure, 30.50 inches, is found in central Asia; the lowest in the northern hemisphere, 29.50 inches, near Iceland; and the lowest of all, 29 inches, in the Antarctic regions.

Figure 276 shows that in July the northern belt of high pressure shrinks

to two centers situated over the oceans, and that central Asia is occupied by a large area of low pressure, falling at the center to 29.40 inches. The southern belt of high pressure is nearly continuous along the tropic, with centers of higher pressure over the oceans and Australia.

In general, the pressure rises from about 29.90 inches at the equator to a maximum of from 30.10 to 30.20 inches at 30° south latitude and 40° north latitude, then falls toward either pole. Toward the south pole the fall is regular and very rapid; toward the north pole it is interrupted by local depressions. Figure 273 shows the variation of pressure along the meridian of 0° in January and of 40° west longitude in July.

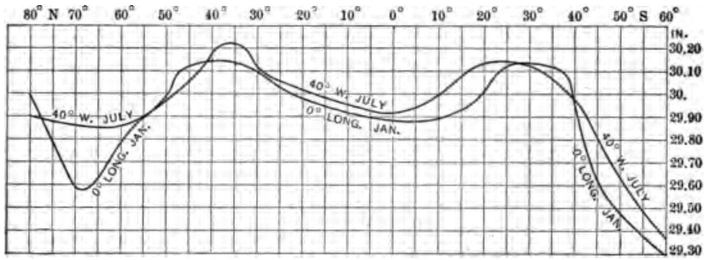


Fig. 273. — **Variation of atmospheric pressure along prime meridian in January, and 40 W. Longitude in July.**

Relations of Temperature and Pressure. — A comparison of the isobaric and isothermal maps reveals the fundamental relations between pressure and temperature. The persistently high temperature in the equatorial belt is accompanied by persistently low pressure. In the seasonal changes the low temperature over the land in winter is accompanied by high pressure, the high temperature in summer by low pressure. These changes and contrasts in both temperature and pressure are more marked in the northern hemisphere than in the southern, and are extreme over Asia, the largest land mass. In January the low tem-

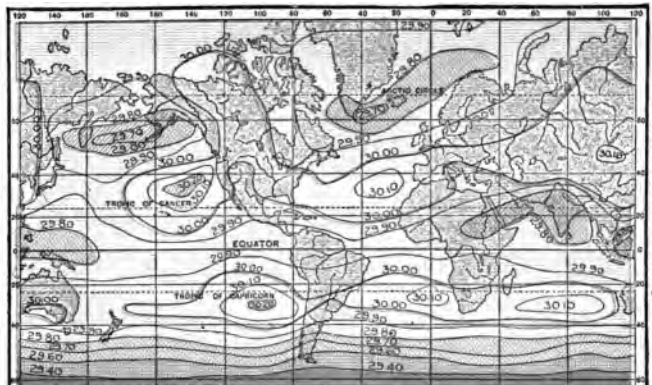


Fig. 274.- Isobars for the year.

Fig. 275.- Isobars for January.

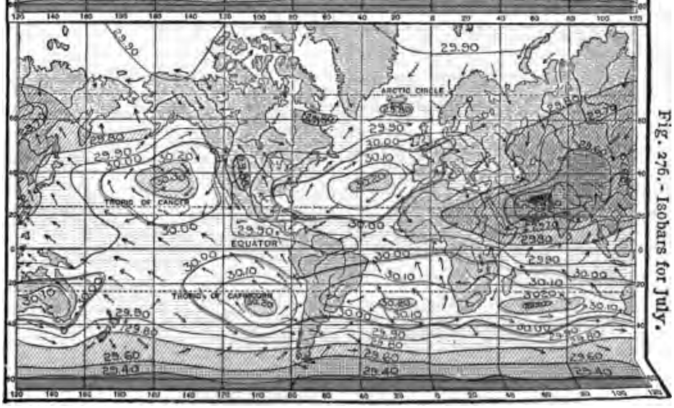


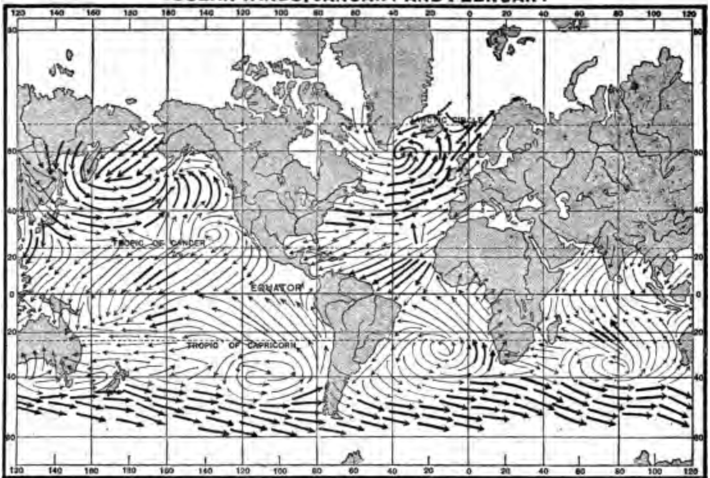
Fig. 276.- Isobars for July.

peratures which prevail over the northern hemisphere are accompanied by prevailing high pressure, and the centers of low pressure occur over the warmer oceans. In July the universal high temperature in the northern hemisphere is accompanied by almost equally widespread low pressure. The centers of high pressure occur over the cooler oceans. These correspondences are in accordance with the well-known law that *the density of air varies inversely with the temperature.*

The fall of pressure with the fall of temperature from middle latitudes toward the poles, and the extremely low pressures in high southern latitudes, are apparent contradictions to this law and must be due to some other cause which overcomes the effect of low temperature. This subject will be considered later in connection with the winds (p. 311).

The Relations of Pressure and Winds. — The direction and force of the prevailing winds have been determined by millions of observations in all parts of the world, but are best known over the oceans from the reports of sailors and naval officers. They are shown upon the wind maps, Figs. 277, 278, and the isobaric maps, pp. 303, 308, 309, by arrows which fly with the wind. The intimate relation which exists between wind movement and the distribution of pressure is clearly evident upon the isobaric map for January. The strong centers of high pressure in the southern oceans are each surrounded by a mass of air which is moving spirally outward, counterclockwise. The strong centers of low pressure in the northern oceans are each surrounded by a mass of air which is moving spirally inward, counterclockwise. In July the strong centers of high pressure in the northern oceans are each surrounded by a mass of air which is moving spirally outward, clockwise. All centers of high and low pressure are accompanied by similar movements, more or less regular and ex-

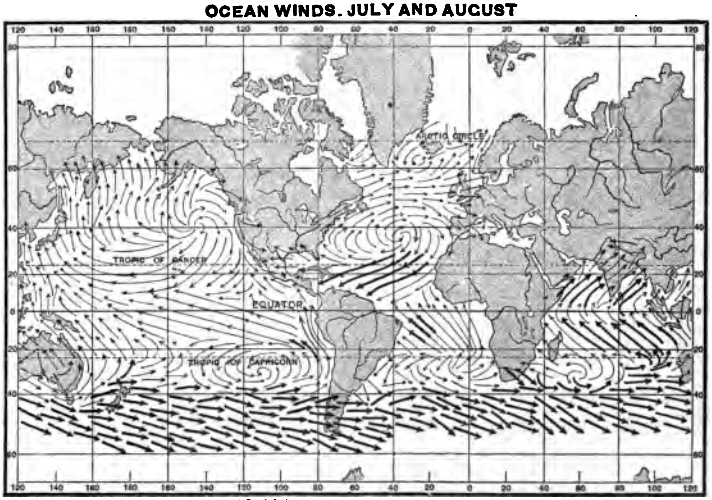
OCEAN WINDS. JANUARY AND FEBRUARY



Less than 18 Miles an hour } Variable Winds
Over " "
Steady "

Fig. 277.

OCEAN WINDS. JULY AND AUGUST



Less than 18 Miles an hour } Variable Winds
Over " "
Steady "

Fig. 278.

tensive. Figure 279 shows that these movements are in accordance with the laws of the winds given on pp. 289, 292 and are the results of gravitation and the rotation of the earth.

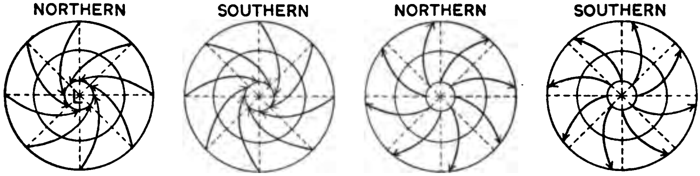


Fig. 279.

Gravitation tends to make air move out from a center of high pressure down the steepest pressure slope, that is, along radial lines. The earth's rotation deflects the moving air to the right of the radial line in the northern hemisphere and to the left in the southern. Gravitation tends to make air move in toward a center of low pressure along radial lines. The earth's rotation deflects the moving air to the right of the radial line in the northern hemisphere and to the left in the southern, but can never make it move up the pressure slope against gravity. The result, in the northern hemisphere, is a curve in the form of the figure 6. As the wind approaches the center, its path becomes more nearly parallel with the isobars, and a whirl or eddy is set up. A movement of air spirally inward toward a center of low pressure is called a *cyclone*. A movement of air spirally outward from a center of high pressure is called an *anticyclone*. Near the center of a cyclone the air moves spirally upward; near the center of an anticyclone there is a downward movement.

Wind Belts. — The arrangement of the centers of high pressure in belts on each side of the equator causes the prevailing winds also to be arranged in more or less definite belts around the earth. The air moves from the belts of high pressure toward the equator on each side and is deflected westward by the rotation of the earth. This constitutes the *trade winds*, from the northeast in the northern hemisphere, and from the southeast in the southern. They blow with great steadiness throughout the year and are called *constant* winds. The air also moves

from the belts of high pressure toward each pole and is deflected eastward. This constitutes the *antitrade* winds or prevailing westerlies, from the southwest in the northern hemisphere and from the northwest in the southern. This movement is most regular and forcible in the southern hemisphere, where the pressure slope is steep and constant. Between these belts of prevailing winds are the belt of equatorial calms, where the air is rising, and the belts of tropical calms, where the air is descending. The complete ideal scheme is shown in Fig. 280.

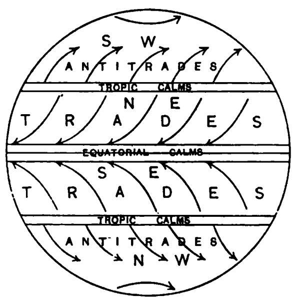
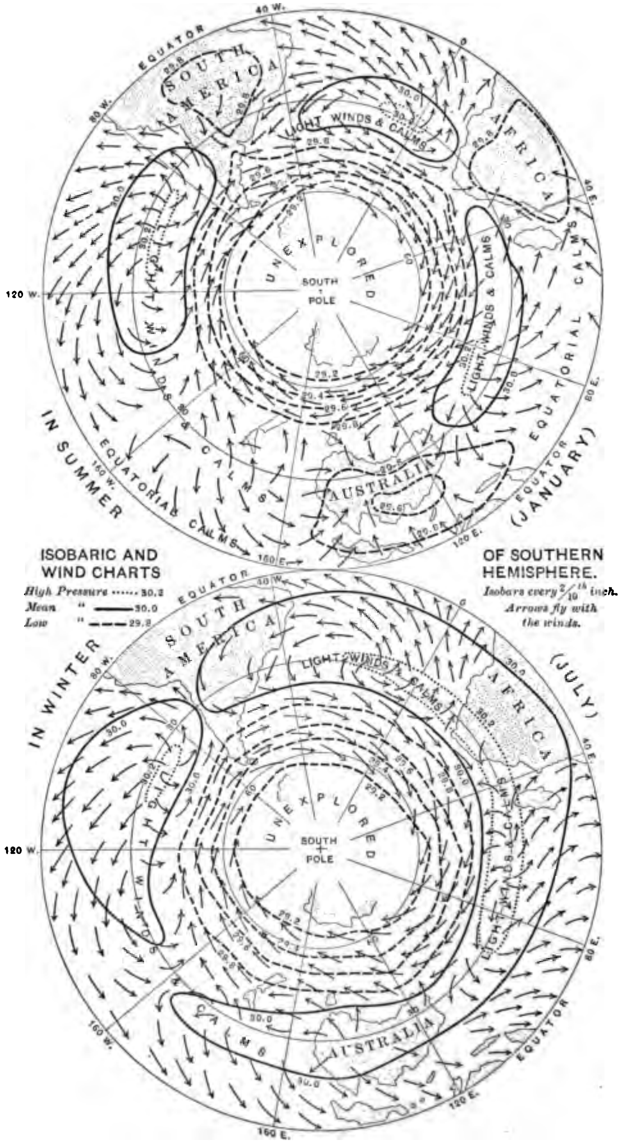


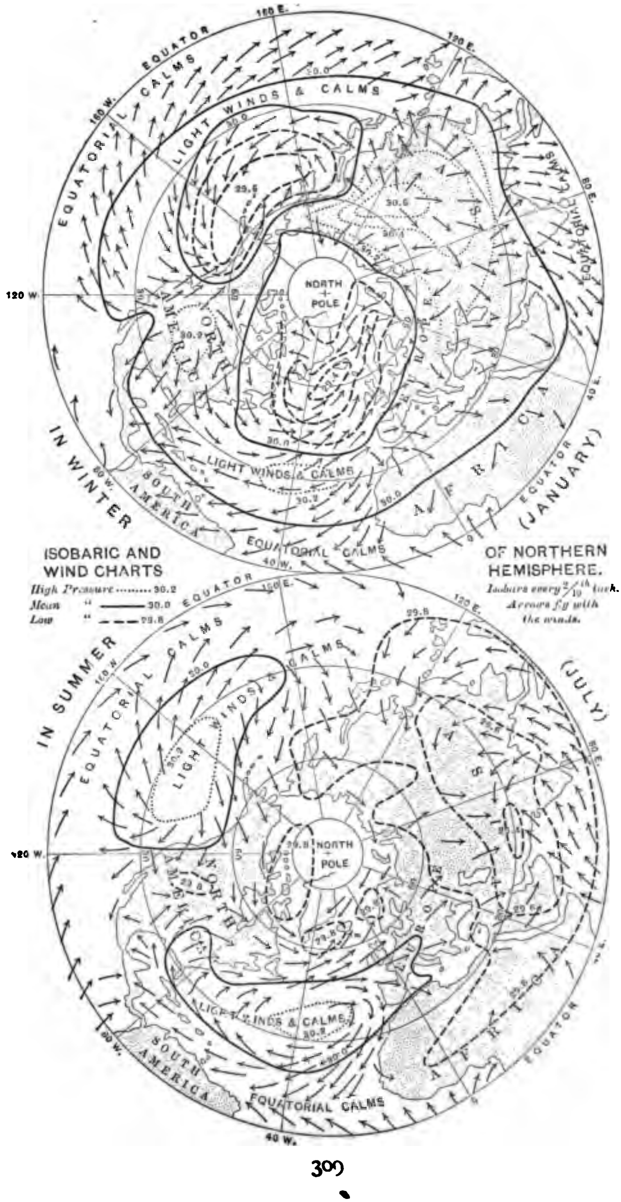
Fig. 280.

Monsoons. — The belts of pressure and prevailing winds are not absolutely fixed, but swing north and south with the sun. The equatorial calm belt coincides not with the geographical equator, but with the thermal equator, and is most variable in position. The belts of the southern hemisphere are nearly constant. The widest departure from the ideal system is brought about by the large and elevated land mass of Asia. In summer this region ceases to be a part of the northern belt of high pressure, and becomes virtually a part of the equatorial belt of low pressure. Consequently the regular northeast trade winds are suspended. The southeast trades cross the equator and continue far northward as south and southeast winds over the western Pacific Ocean and eastern Asia, and southwest winds over the Indian Ocean and southern Asia. In winter the regular northeast trades prevail over these regions. These southerly summer winds and northerly winter winds are called *monsoons*.

The Polar Whirls. — The air moving from the belts of high pressure toward the poles is deflected eastward, and acquires a high velocity. It thus forms, especially in the southern hemisphere, a great cyclonic whirl from west to east around the polar regions, rising gradually as it nears the center (see maps, pp. 308, 309).



ISOBARIC AND WIND CHARTS
OF SOUTHERN HEMISPHERE.
IN SUMMER
(JANUARY)
IN WINTER
(JULY)
High Pressure 30.2
Mean " 30.0
Low " 29.8
Isobars every 2/10th inch.
Arrows fly with the winds.
SOUTH AMERICA
AFRICA
AUSTRALIA
UNEXPLORED
SOUTH POLE
LIGHT WINDS & CALMS
EQUATORIAL CALMS
EQUATOR
40 W.
0
40 E.
80 E.
120 E.
160 E.
160 W.
120 W.
80 W.


ISOBARIC AND
WIND CHARTS
OF NORTHERN
HEMISPHERE.
IN WINTER
(JANUARY)
IN SUMMER
(JULY)
High Pressure 30.2
Mean " ——— 30.0
Low " - - - 29.8
Isobars every 2/10th inch.
Arrows fly with
the winds.
NORTH
POLE
EQUATOR
EQUATORIAL CALMS
LIGHT WINDS & CALMS
NORTH AMERICA
SOUTH AMERICA
EUROPE
ASIA
AFRICA
160 E.
120 E.
80 E.
40 E.
160 W.
120 W.
80 W.
40 W.

There is some evidence to show that at the very center of the south polar whirl there is a small anticyclone, from which southerly winds blow outward with great violence.

In the northern hemisphere the polar whirl is much interrupted by the land masses, and in summer it almost disappears. In winter it is divided into two portions which circulate around the centers of low pressure over the north Atlantic and north Pacific oceans. Probably a portion of the air moves in a circuit which incloses both centers.

The General Circulation of the Atmosphere. — Thus far only the movements in the lower layers of air next to the surface of the land and water have been considered.

Our knowledge of the upper air by direct observation is much less extensive and accurate than of the lower air. It has been gained by means of observations made upon mountains, by occasional balloon ascensions, from the drift of high clouds and volcanic dust, and by means of kites and unmanned balloons carrying self-recording instruments, such as the thermograph and barograph (see Appendix, pp. 402, 403), to great heights.

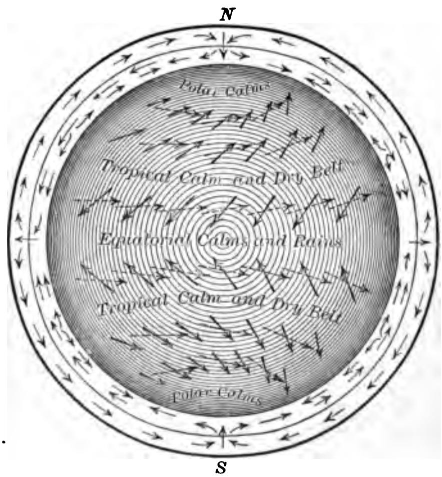


Fig. 281. — Direction of primary air currents. (After Ferrel.)

The movement of the upper air is everywhere toward the poles, with an eastward deflection. In other words, the polar whirls in the upper air cover the whole of each hemisphere and have a common circumference at the equator. As the currents approach the poles, they descend and return at intermediate heights toward the equator. Below

this system of circulation, and fed by it, are the surface currents with which we are most familiar. The whole system of atmospheric circulation is shown by map and section in Fig. 281.

On the map or shaded part of the figure, the complete arrows show the direction of surface currents, and the broken arrows that of upper currents. The mass of warm air rising from the equatorial regions, at and above a height of two miles, turns to the northeast and southeast. By a very circuitous, spiral course, passing round the earth many times on the way, but moving with increasing velocity, it approaches the poles and gradually descending returns toward the equator. At the tropical belts of high pressure, the return currents drop down to the surface of the earth and continue as the trade winds to the equator. A part of them turn back at the tropics and form the prevailing surface westerly winds or antitrades, which rise as they approach the poles and rejoin the intermediate return currents. Figure 282 shows a diagram of the upper currents and a simplified section of the whole system.

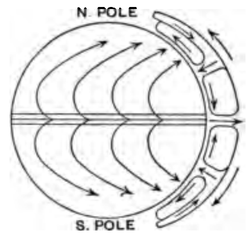


Fig. 282.

Effect of the Polar Whirls. — The effect of the polar whirls may be seen in the rapid rotation of water in a pan or bowl. The centrifugal force throws the water away from the center, where the surface becomes depressed, and piles it up around the sides, where the surface becomes elevated, as in Fig. 283. The water being deeper at *A* and *B* than at *C*, its pressure upon the bottom is proportionately greater. A similar effect is produced by the whirl of the air around the polar regions. It is thrown away from the polar regions and piled up around the circumference of the whirl. There is less air above the polar regions than above latitude 30°-40°, and the atmospheric pressure is correspondingly low at one place and high at the other. Thus the centrifugal force of the polar whirl makes the pressure low in spite of the low temperature. The position of the tropical belts of high pressure is a resultant of the high temperature of the equatorial regions on one side and the polar whirls on the other.

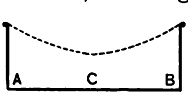


Fig. 283.

CHAPTER XXVII

STORMS

Cyclones. — The regularity of the general system of prevailing winds is subject to local and temporary disturbances called *storms*. A storm is usually characterized by an increase of wind velocity, accompanied by precipitation. A large majority of storms are cyclonic whirls in which the air moves spirally toward a center of low pressure. The isobars are seldom circular, but extend in more or less elliptical curves around the low center. The general course of the winds is across them, but at a smaller angle as the center is approached, as shown in Fig. 279. The motion becomes more rapid and more nearly circular as the air rises around a central calm. The cyclonic or vortex movement may be regarded as the normal air movement on a rotating earth. Each of the great polar whirls in the upper air covers half the earth. Within these are smaller cyclones of the second, third, and even fourth order, down to little dust whirlwinds a few feet in diameter. The temperate or mid-latitude regions of the northern hemisphere are much frequented by cyclonic storms which are of great extent, but not violent. They often attain a diameter of more than a thousand miles and bring their characteristic weather conditions to a correspondingly large area. While the movement of the air at every point within their circumference forms a part of a cyclonic system, the center of rotation moves forward in a general easterly direction at the average rate of about thirty miles an hour. Thus the whirl travels through the atmosphere

as an eddy moves through still water, constantly taking in new air in front and dropping out air behind. The air rises as it approaches the center, and at the height of a mile or more spreads out in a reverse direction toward the circumference.

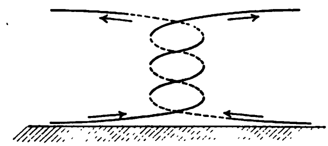


Fig. 284. — Upward movement of air at center of a cyclone.

The maps, Figs. 286–288, show the progress of a cyclonic storm across the United States and the weather conditions which accompany it. As in this example, the isobars encircling the center of low pressure are usually more or less elongated in a north-south direction. The result is that in the front or eastern half of the storm the prevailing winds are from the southeast and south, and in the rear or western half from the northwest and north. Over a small area on the north side east winds occur, and on the south side west winds. The southerly winds coming from the Gulf of Mexico and Atlantic are warm and damp, and as they advance northward are cooled by radiation and conduction. Consequently they bring cloudy weather with rain or snow, which on account of the rising and mixture of air around the center often extends over a large area on all sides. On the west side the northerly winds coming from the interior of the continent are cool and dry, and as they advance southward are warmed. Consequently they evaporate the clouds and bring clear weather. As the storm advances, these two strongly contrasted types of weather prevail in succession at every point in its path. Fig. 285 shows the curves of pressure in a cyclone; notice that the changes of pressure are greater and more rapid along *BA* than along *ED*. See also Fig. 301.

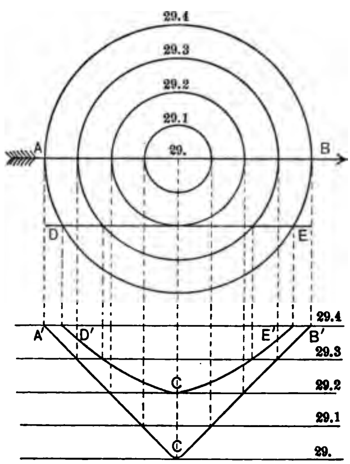


Fig. 285.

(——— Isobars. ------- Isotherms. Arrows fly with the wind.)

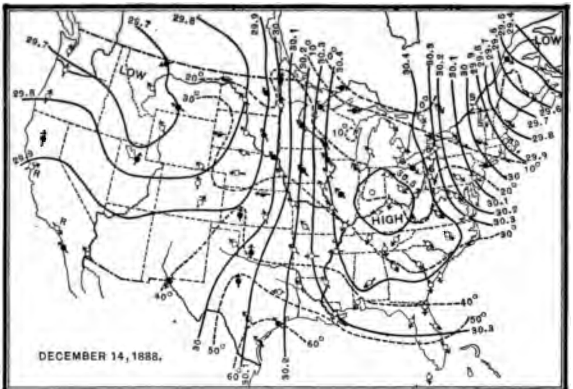


Fig. 286.

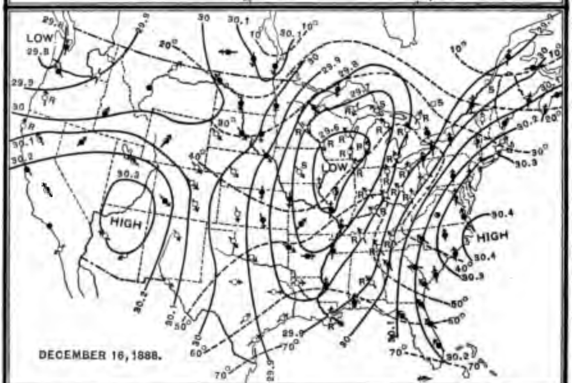


Fig. 287.

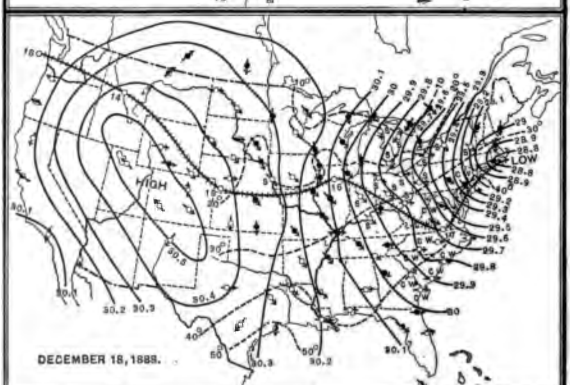


Fig. 288.

Anticyclones. — The areas of relatively high pressure between the cyclones sometimes take the form of irregular "ridges," but more often they appear as definite centers of high pressure, or *anticyclones*, as in Figs. 286–288. The conditions in an anticyclone are the exact reverse of those in a cyclone, as shown on p. 306. At the center the air is descending, and when it reaches the surface of land or water it spreads down the pressure slope in all directions. The rotation of the earth gives it a spiral motion, clockwise in the northern hemisphere. The anticyclonic centers move eastward along paths similar to those of cyclones. On the eastern side the winds are chiefly from the north and northwest, and bring cold, clear weather. On the western side the winds are chiefly from the south and southeast, and bring higher temperature to the regions over which they blow; but owing to the fact that these currents are supplied with dry air which descends from above at the center and is warmed by compression, they do not usually bring cloudy or rainy weather, as do the winds in front of a cyclone.

Warm and Cold Waves. — The southerly winds in front of a cyclone carry the isotherms northward, as shown in the eastern part of the map, Fig. 287. As the cyclone advances eastward, it carries a wave of rising temperature in front of it. This effect, however, is not usually so pronounced as the cold wave which precedes an anticyclone. The northerly winds in front of an anticyclone cause the isotherms to curve away from the center of high pressure, as shown in Figs. 289–291. When a cyclone passes across the southeastern part of the United States, followed by an anticyclone in the northwest, a wave of falling temperature spreads over the greater part of the country. In winter freezing temperatures may be carried nearly to the tropic and zero weather to the Gulf states. In the northwest the air is sometimes filled with extremely fine ice crystals driven by a high wind. Such a storm is locally known as a *blizzard*. In the north and east, the storm usually brings a heavy fall of snow.

(——— Isobars. - - - - - - - Isotherms. Shaded areas represent rain or snow.)

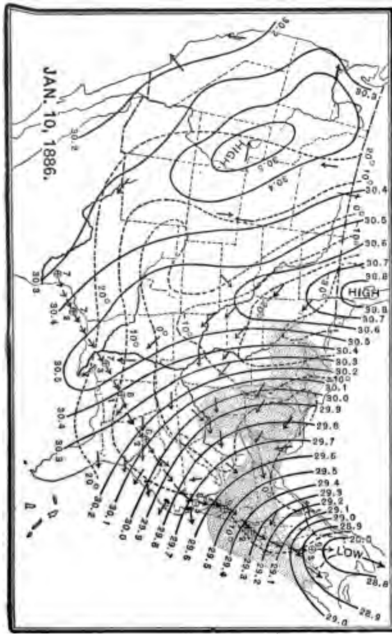


Fig. 291.

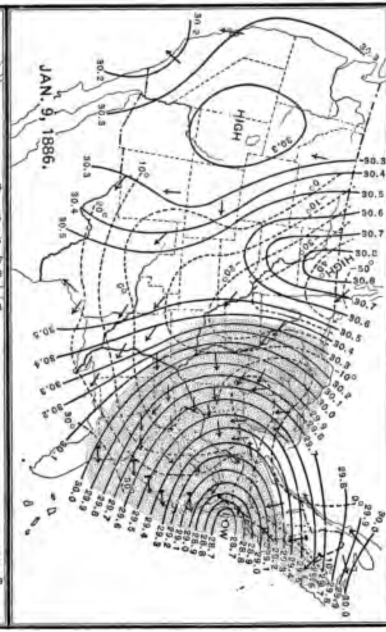


Fig. 290.

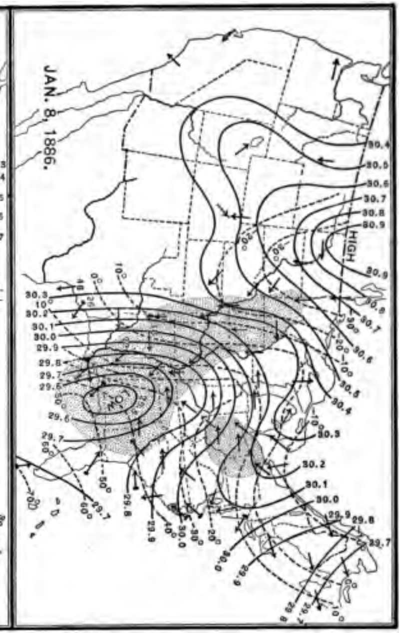


Fig. 289.

The Procession of Cyclones and Anticyclones. — Through the greater part of the year, but especially in the winter months, the eastern part of North America is traversed by a more or less irregular but continuous procession of cyclones and anticyclones which succeed one another at intervals of a few days.

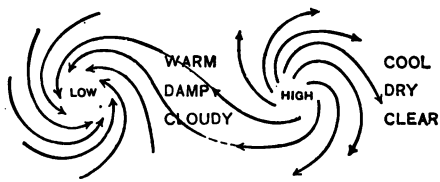


Fig. 292.

The result is a rapid succession of weather changes, which are often sudden and decided in character. If the cyclones and anticyclones all pursued the same path at regular intervals, the result would be as shown in Fig. 292. An approach to this condition appears upon the maps, Figs. 286–288, but it usually happens that the paths of the different centers are not uniform and the spacing between them is unequal. Thus the order of their occurrence is irregular. Cyclones and anticyclones also vary greatly in development. Some are small and feeble, some large and strong, and the degree of control which they exercise over the weather conditions varies accordingly.

Figures 286–288 show the progressive development of a temperate cyclone. On 286 the low center in Montana, with a pressure of 29.7 inches, is surrounded by only three isobars, which are far apart. The pressure slope is gentle, and the winds are light and irregular. On 287, the center has moved to Illinois, with a pressure of 29.6 inches, and is surrounded by five isobars. The slope is steeper, the winds are stronger and show very little variation from a regular spiral whirl. On 288, only the rear half of the cyclone is shown, but the pressure at the center, now off the New England coast, has fallen to 28.8 inches and it is surrounded by fourteen isobars, which are closely crowded. The slope is very steep, and the velocity of the wind is high, amounting near the center to a gale dangerous to shipping. The crossed line shows the path pursued by this cyclone across the United States and

the position of its center from day to day. The maps, Figs. 289–291, show a cyclone which developed very rapidly, having on the second day nineteen isobars, and a difference of pressure between center and circumference of 1.80 inches. Two low centers may combine into one, or a single one may break up into two. Cyclones usually pass off into the Atlantic Ocean, where they gradually die out, or they may continue across Europe as far as central Asia.

Storm Paths. — On Fig. 293 the paths of many individual cyclones are shown. The heavy line marks the path of the greatest number. Fig. 304 shows favorite paths across the United States.

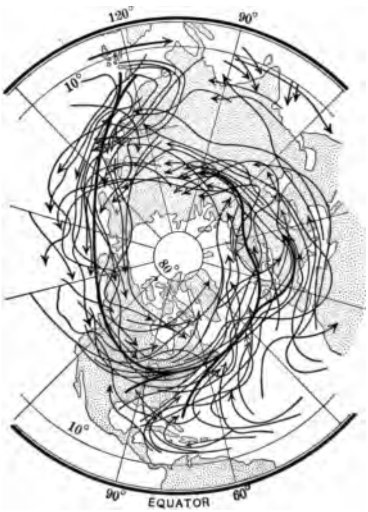


Fig. 293.

Weather Maps. — The daily weather maps issued by the United States Weather Bureau should be consulted for examples of cyclones and anticyclones. The maps for January, February, and March furnish the best and most numerous specimens. The local weather conditions as observed by the student should be compared each day with those shown by the weather map. Observation and map study carried on together for two or three months will make clear the laws which govern the apparently capricious changes of the weather, and will enable the student to predict those changes with a fair degree of accuracy. Weather maps may be obtained by addressing the local officer in charge of the nearest observing station (see Appendix, p. 411).

Tropical Cyclones. — In the region between the tropics, cyclones occur which are much smaller than those of temperate regions, but are of proportionately greater violence. They are developed over the western parts of the

oceans, those in the north Atlantic being called *hurricanes*, and those of the Pacific and Indian, *typhoons*. They originate in the belt of equatorial calms when farthest from the equator. From a small beginning they increase to a diameter of 300 to 500 miles. At the same time the velocity of the wind increases to a degree which becomes destructive to shipping upon the seas and to buildings, forests, and crops on land. After a career which lasts many days or even weeks, they gradually die out. Their paths are more uniform and regular than those of temperate cyclones. They move westward and poleward at right angles to the trade winds, until they reach latitude 25° to 30°, where they turn rather abruptly into the path of the antitrades and move poleward and eastward.

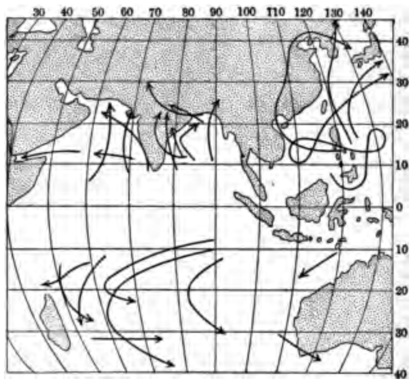


Fig. 294. — **Paths of typhoons.**

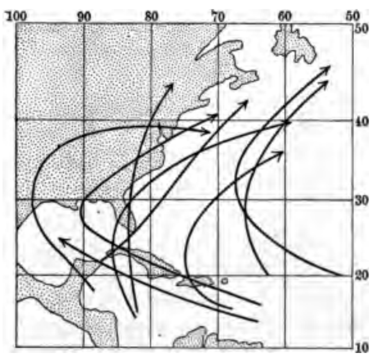


Fig. 295. — **Paths of hurricanes.**

West India Hurricanes. — In the months of August, September, and October the West India Islands are subject to cyclones which arrive from the east and southeast, and depart toward the northeast along or near the coast of the United States. The winds acquire a spiral movement which becomes nearly circular around a central region of calm

which is from ten to twenty miles in diameter. The circumference of the storm is marked by a slight rise of the barometer and the appearance of fine cirrus clouds which form in the air blowing out from the top of the approaching whirl. The barometer begins to fall, the wind freshens, and the cloud mass becomes more dense. As the center comes nearer, the wind rises to a gale, and the clouds gather into a black mass of nimbus from which heavy rain falls. Within about fifty miles of the center, the barometer sinks rapidly, the wind attains full hurricane strength, the clouds are so dense as to change daylight into the darkness of midnight, and the rain pours down in torrents, accompanied by frequent flashes of lightning. At the center of the whirl these conditions change very abruptly. The wind falls to a calm, the rain ceases, and the clouds break away, showing a clear sky. The barometer now reaches its lowest point, which may be less than 27 inches. This calm, clear, central space is called the *eye of the storm*, and it may occupy an hour or two in passing. Then the hurricane begins again with sudden and extreme violence, but the winds are reversed in direction. All the phenomena observed in the first half of the storm are repeated in reverse order but in somewhat more rapid succession. The barometer rises, the violence of the wind gradually abates, the rainfall becomes more gentle, the dark nimbus clouds lighten and at last disappear, the lofty cirrus clouds recede, and the storm has passed away.

Destructiveness. — Tropical cyclones are much dreaded by ship captains. When the warning signs of their approach are observed, the ship is put upon a course which usually takes it out of the path of the central portion. If caught in the most violent part of the storm, it is liable to be wrecked by the force of the winds and waves, and can hardly escape without serious injury. In passing over the land the hurricane causes great destruction to life and property. Hardly anything of value is left in its path. The smaller islands are sometimes literally swept clean of trees, crops, buildings, and almost of population. Perhaps the most complete ruin is accomplished along the coast, which suffers from the combined action of wind and wave; for the low atmospheric pressure at the storm center and the inblowing winds coöperate to produce a heaping up of the water to a height of many feet above the usual sea level.

Causes of Tropical Cyclones. — The evidence seems to point clearly to the conclusion that a tropical cyclone is

a part of a system of convection currents set up and maintained by a difference of temperature and subject to the influence of the earth's rotation. Under the direct rays of the tropical sun the lower air becomes excessively heated and in contact with the sea excessively humid. It is thus made less dense than the air which overlies it — a condition which is as unstable as would be a layer of oil under a layer of water. Sooner or later the lighter air below breaks through the heavier air above and drains away upward like a draught in a chimney. The surrounding air crowds in from all sides toward the bottom of the updraught and soon acquires the usual spiral motion.

As the air currents approach the center the rapidity of rotation becomes so great that centrifugal force overcomes gravitation and prevents the incoming winds from reaching the center, which is left as a calm and comparatively emptied of air, like the core in the center of a water eddy. The air escapes by a spiral movement upward, and since there is no more efficient cause of cooling and condensation than the expansion of rising currents (see p. 282) the great mass of nimbus cloud and the downpour of rain necessarily follow. In the eye of the storm the air is not rising and there is probably even a slight downward draught, which tends to produce a clear sky.

Duration and Force. — The amount of energy required to maintain the high velocity of a hurricane in a mass of air 300 miles in diameter is enormous and can not be derived from the original heat energy which started the updraught. One typhoon has been known to continue for thirty-five days and to travel the whole length of the heavy line on Fig. 293 from the Philippine Islands to central Europe, a distance of more than 14,000 miles. A very large supply of energy is derived from the liberation of latent heat which accompanies the rapid condensation of water vapor in the rising column. Thus the cyclone maintains at its own center a virtual furnace which keeps up the temperature as long as water vapor is supplied for condensation. When it passes over the land and is fed with dry air, it rapidly loses force and is finally overcome by friction.

Course. — The westward and poleward course of a cyclone within the tropics is probably a resultant of two forces. Its lower portion is in

the current of the trade winds, which tend to carry it westward, while its upper portion rises into the current of the antitrades, which tend to carry it poleward. The result is movement in a direction between the two. Beyond the tropics it follows the northeastward or southeastward drift of the antitrades.

Origin of Temperate Cyclones. — The conditions under which temperate cyclones originate are so different from those which prevail at the birthplace of tropical cyclones that it seems impossible to attribute them to similar causes. Temperate cyclones are more frequent and violent in winter than in summer. Many of them are developed over land where the air is dry and cold, and the conditions are unfavorable to convection. The theory that temperate cyclones are eddies set up around the margin of the polar whirl is a plausible one. The map on p. 309 shows that the north polar whirl in winter is divided into two whirls around the centers of low pressure in the north Atlantic and north Pacific oceans. The margin or circumference of the whirl is along the axis of the belt of high pressure which surrounds these areas of low pressure, and Fig. 293 shows that the most frequent path of cyclones nearly coincides with this axis. The Atlantic whirl seems to be more prolific of cyclones than the Pacific. The oblique flow of the upper and lower winds into the ever narrowing space around the pole, the return of the air at intermediate levels, and the friction of continents may well give rise to local crowding and disturbance, and the temperate cyclones may be eddies driven by the general winds, like the eddies produced in a river where its banks and bottom are irregular.

Form of Temperate and Tropical Cyclones. — These whirling masses of air are not tall and slender columns as we are apt to imagine, but relatively thin, flattened disks, not more than five miles in thickness and *from 300 to 1500* miles in diameter. A circular disk one inch in diam-

eter cut from a leaf of this book would not be too thin to represent their average proportions.

Tornadoes. — A tornado is a small and violent cyclone which appears as a funnel-shaped cloud with the small end down. Its formation or approach is preceded by the rapid movement of cloud masses toward some central point. The clouds may look as if lighted up by a great fire or like dense volumes of smoke, or may have a peculiar greenish hue. The funnel-shaped cloud descends as a pendant from the larger cloud mass, like an elephant's trunk, and dangles above or upon the ground, writhing and twisting about, touching here and there, and often skipping over a portion of its regular path. The tornado travels toward the northeast, in the northern hemisphere, at the rate of about forty miles an hour, and seldom continues more than two hours. Along a path which varies in width from a few rods to half a mile, it is extremely destructive. The velocity of the wind in the whirl often reaches 200 miles per hour and occasionally twice as much. Nothing except the solid earth itself can withstand its force. It creates a deafen-

Fig. 296. — How a tornado looks.
(Newcastle, Neb., April 30, 1898.)

ing roar like the rumble of a railroad train over a bridge, greatly intensified. In front there is a gentle southerly breeze or a dead calm with oppressive heat. The tornado passes in a minute or two and is followed by a sudden fall of temperature.

Through a forest a tornado cuts a swath like that of a mower through a meadow, the trees being twisted off or uprooted. From plowed fields it removes the loose soil, and sucks up the water from small ponds, leaving them dry. Even large boulders and masses of iron are taken up and transported hundreds of feet. Buildings of all kinds which stand in its way are demolished, and their fragments scattered over the surrounding country. Animals and human beings are lifted and whirled about and sometimes transported a half mile or more. They are often killed by flying débris and sometimes seem to be literally torn in pieces. Heavy structures are removed from their foundations and locomotive engines lifted from the rails. The smaller work of a tornado is equally impressive, such as the stripping of feathers from fowls and the clothing from persons. Wire hairpins have been driven through fence boards and straws driven into oak wood. Almost any story of a tornado's energy may be true, because the truth is beyond the power of human imagination to invent. A part of a house may be reduced to fragments while the rest is left undisturbed. People have been carried long distances and deposited unhurt. Heavy objects are removed and light and fragile ones left in place. Fragments of furniture from the same room or from the same piece are often widely scattered in opposite directions. These and other mysterious freaks are probably due to irregular and confused currents in the general whirl. The walls of buildings are often thrown outward as if by an explosion from within.

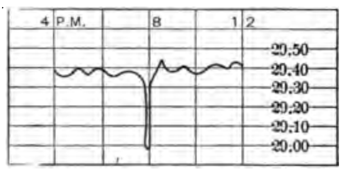


Fig. 297. — Pressure during the passage of a tornado.

Tornadoes always occur some hundreds of miles to the southeast of the center of a temperate cyclone, where a current of warm, moist air is underrunning a layer of colder air. They occur chiefly in the summer months and in the afternoon of hot days. These conditions are very favorable for the starting and maintenance of strong convection currents.

Tornadoes seldom occur singly, but in groups of three or more, which follow parallel paths. As many as forty have been reported from one locality in one day. The average number in the United States is about 150 per year. They are most frequent in Kansas, Iowa, Missouri, Illinois, and Georgia, and are almost unknown north of the forty-fifth parallel and west of the one hundredth meridian.

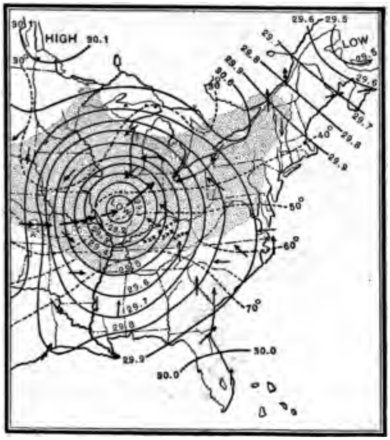


Fig. 298. — Location of tornadoes in a cyclone. (Shown thus: x x x.)

Spouts. — A tornado at sea takes the form of a whirling column which extends from the clouds to the water surface and is called a *waterspout*. It is formed by the usual tapering funnel, which descends from the clouds and is met by rising water below. The greater part of the column, however, is composed of cloud and rain. When it passes over a ship, as occasionally happens, there is a deluge of fresh water.

In the desert columns of whirling sand are of frequent occurrence and are maintained for several hours. The small whirlwinds common on dry, warm days are worthy of careful observation, since they present many of the essential features of cyclones on a small scale.

Thunderstorms. — The rapid condensation of water vapor is often accompanied by the generation of electricity, and when this occurs to such a degree as to produce frequent discharges of lightning from cloud to cloud or between the clouds and the earth, the disturbance is called a *thunderstorm*. A local ascending current of warm, moist air develops at its summit a cumulus cloud with a flat base. This increases in height and area for several hours, until rain begins to fall. The air is cooled and pressed downward until the current in the central portion is reversed. The column of descending air spreads out at the bottom and

becomes surrounded by a current of ascending air which continues to supply moisture to the cloud above. At the center the pressure is high and the temperature low; at the circumference these conditions are reversed, and between the two there is a zone of strong contrasts and steep gradients marked by squalls of violent wind and rain.

Fig. 299. — Clouds and winds in a thunderstorm which is moving toward the right.

Progressive Thunderstorms. — A thunderstorm is very apt to take on a progressive movement in the direction of the general air current (eastward in the United States), and to broaden out so as to present a convex front, which increases in length. The cloud mass may attain a length of 100 miles and a breadth of 30 miles, and reach to a height of 5 miles. Its front edge of cirro-stratus, with rolling festoons of cloud below, extends from 10 to 50 miles in advance of the rain. The rate of movement is from 20 to 50 miles an hour, and it may continue from 2 to 12 hours. As the storm approaches, the sky is gradually overcast, the air is hot, breathless, and oppressive, the barometer falls, and the distant thunder is heard. In front and below there is a strong outrush of cool air which lasts but a few minutes and is followed by the dash of rain. The temperature falls rapidly, sometimes as much as twenty degrees in a half hour, the barometer jumps suddenly upward, and the darkness of the downpour is broken by vivid flashes of lightning. The rainfall seldom lasts more than an hour unless a second storm follows close upon the first.

Cloudbursts. — In tornadoes or thunderstorms strong ascending currents may carry up and sustain the rain or hail until an excessive quantity has accumulated aloft, which sooner or later falls in an almost solid mass of water. Such events are popularly known as *cloudbursts*.

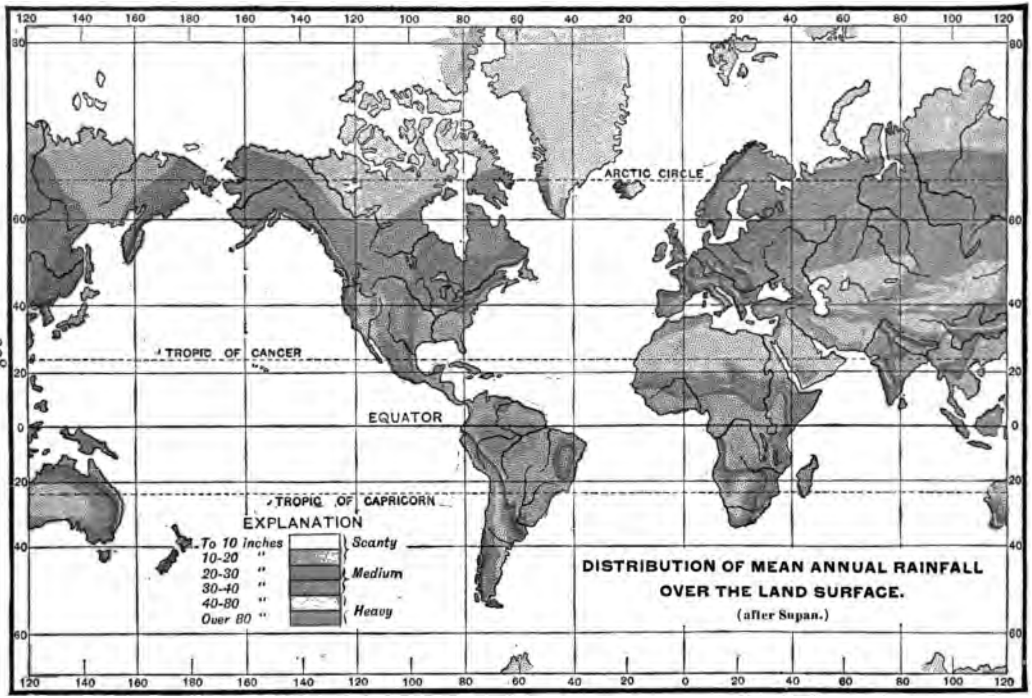
CHAPTER XXVIII

RAINFALL

Causes of Rainfall. — The general causes and conditions which promote condensation of water vapor and the fall of rain and snow have been discussed in Chapter XXIII. The distribution of rainfall over the earth remains to be considered. On account of the absence of permanent observing stations at sea, the rainfall has never been accurately measured there. The facts as observed upon land are shown on maps, pp. 328, 330, 331. The conditions necessary for considerable rainfall anywhere are (1) a large body of water from which sufficient evaporation may occur, (2) air currents to transport the vapor over the land, and (3) some agency for cooling and condensing the vapor. The first requisite is supplied almost solely by the sea, the second by prevailing winds, and the third by winds and by elevations of the land. On account of the intimate relations between the winds and the supply of moisture, each wind belt is characterized by a peculiar type of rainfall, while the varied relief of the land breaks up the belts into more or less distinct and contrasted portions. Hence the patchwork appearance of the maps.

Equatorial Rains. — In the region between the tropics the rainfall is generally large and is the result of two processes: (1) the rising of the air in the equatorial calm belt, and (2) the flow of the trade winds from the ocean over the land.

In the belt of equatorial calms, heavy rains are of almost daily occurrence, and are produced by the mechanical cooling of rising air.

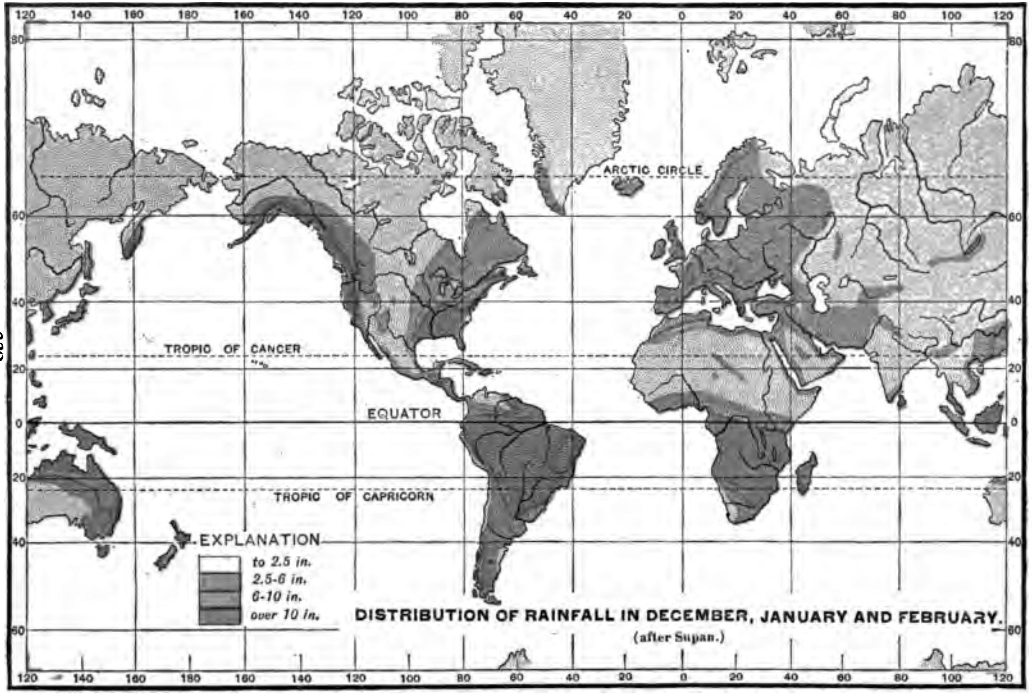


DISTRIBUTION OF MEAN ANNUAL RAINFALL OVER THE LAND SURFACE.

(after Supan.)

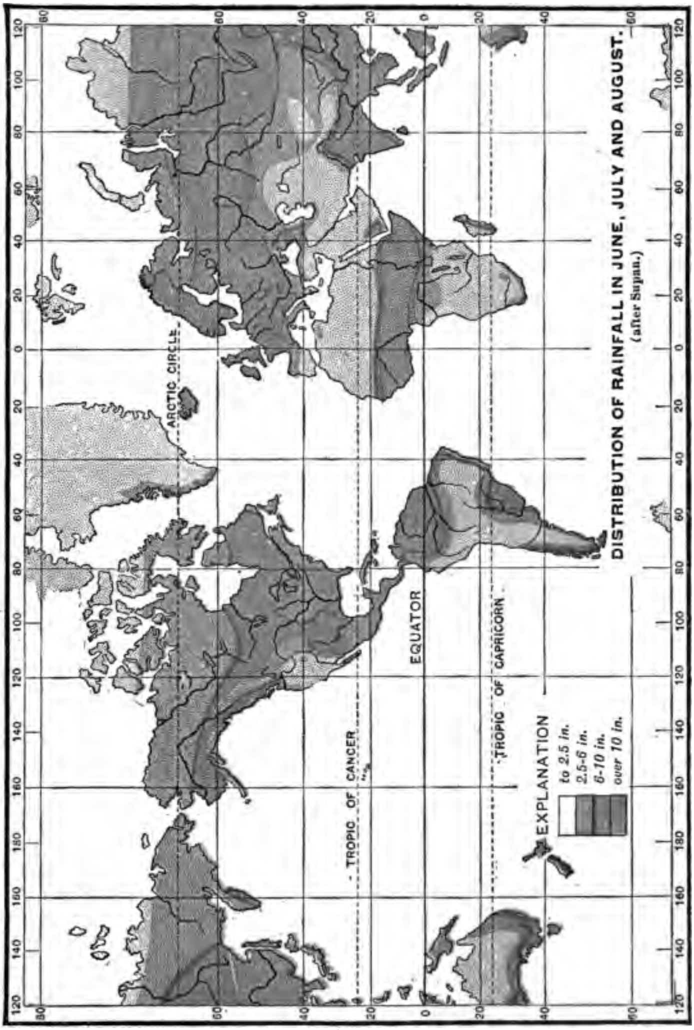
The mornings are usually clear, but cumulus clouds soon begin to form, which continue to grow until afternoon, when thunderstorms occur, often succeeding one another into the night. These conditions accompany the equatorial belt of low pressure in its migrations and therefore pass over the regions within its range twice a year. Near the northern and southern limits reached by the belt the two rainy seasons merge into one and occur in summer when the sun is nearly vertical. At the middle of the belt, rainy seasons occur in the spring and fall. Those months during which the trade winds blow without interruption are dry except where winds from the sea strike the side of a plateau or mountain range and are compelled to ascend.

In January, on account of the low pressure over the southern land masses, the rains extend beyond the southern tropic in South America and Africa and reach the northern coast of Australia. In July they cross Central America, the West Indies, and central Africa, and are carried by the monsoons to the coast lands of Asia from India to Japan. Over the regions between these limits, with few exceptions, the rainfall ranges from 40 to over 80 inches per year. In South America there is an excess on the northeast and southeast coasts due to the highlands, which extend across the course of the trade winds and act as very efficient condensers. The wide extent of heavy rainfall over the lowlands of the Amazon basin is probably due to the diminished speed of the trade winds by friction in passing over the land. The currents from the ocean supply more air than can pass in a layer of uniform thickness, and the air is compelled to rise, as the surface of a stream of water is raised in passing over an obstruction in its bed. On the west coast of South America there is a deficiency of rainfall, because the lofty chains of the Andes permit little moisture to pass over them. In Africa there is a deficiency in the eastern peninsula where the monsoons blow from the land. In southeastern Asia there is a large excess of rainfall in summer, but on account of the varied relief it is unequally distributed. The southwest coasts of India and Indo-China and the Ganges and Brahmaputra basins receive excessive rain (80–400 inches), most of which falls in the summer; while over the Dekkan plateau there is a deficiency. The Khasia hills, north of the head of the bay of Bengal, receive the heaviest rainfall in the world, averaging 493 inches per year and amounting in some years to 600 inches. Over 438 inches falls in five summer months, and more than 40 inches has been recorded in a single day.



DISTRIBUTION OF RAINFALL IN DECEMBER, JANUARY AND FEBRUARY.

(after Supan.)



DISTRIBUTION OF RAINFALL IN JUNE, JULY AND AUGUST.
(after Supan.)

Tropical Rains. — In the tropical belt of high pressure the air is warmed by compression as it descends, and hence brings little rain. As it shifts north and south, it is followed by the trade winds on the equatorial side and by the temperate cyclones on the polar side.

The northern tropical belt is much less regular and well-defined than the southern. In summer it nearly ceases to exist over the land, and its place is taken by the trades. Where these blow from the ocean, against highlands, as in Central America, they bring a wet season; but where they blow from the land, as in the Mediterranean region and southwestern Asia, they bring a dry season. By a combination of these conditions, southwestern United States, north Africa, Arabia, Persia, and the region of the Caspian and Aral seas are perennially dry. Of these regions, the Sahara and Arabian deserts are the largest and driest in the world.

The southern tropical belt in winter crosses southern South America, south Africa, and central Australia, causing a deficiency of rainfall at that season. A narrow strip on the coast west of the Andes in northern Chile forms the desert of Atacama, and a larger area in southwest Africa the Kalahari desert, while central Australia contains the largest desert in the southern hemisphere. In summer the tropical belt lies to the south of all the land except South America.

Rains of Middle Latitudes. — Beyond the tropical belts of high pressure rains are brought either by the westerly anti-trades or by temperate cyclones; consequently the rainfall varies more along east-west than along north-south lines.

In winter the west coast of North America has abundant rainfall as far south as 35°, but on account of the mountains near the coast it extends but a few hundred miles inland. The coast of southern Alaska, being reached by perennial southwest winds, has rain at all seasons, but south of 40°, on account of the cessation of southwest winds in summer, rain is scant or wanting in that season. Central North America, from Mexico to the Arctic Ocean, is dry, partly from being too far inland, and partly on account of the mountains along the Pacific coast. The Rocky, Wasatch, and other mountains and plateaus which rise above 8000 feet receive a moderate rainfall. Eastern North America from the Gulf of Mexico to Hudson Bay enjoys a rainfall above 30 inches,

increasing to 60 inches on the Gulf coast. This is due chiefly to the cyclonic storms which bring moisture from the south and southeast, and to the absence of elevations sufficient to shut it out. The Gulf of Mexico appears to furnish the larger quantity, but the southerly winds are fed in summer by the northeast trades from the Atlantic and sweep far inland toward the continental center of low pressure. The rainfall is well distributed throughout the year, but is generally heavier in spring and summer than in autumn and winter. The increased frequency of cyclones in winter nearly compensates for the lower absolute humidity of the air. The largest mean annual rainfall in North America is at Sitka, Alaska, 112 inches, and at Neah Bay, Washington, 105 inches; while the Mohave desert, California, has the smallest recorded rainfall in the world, 1.85 inches.

The rainfall of Europe and northern Asia is chiefly supplied by the westerly winds from the Atlantic. It therefore decreases from west to east and is greatest in summer and autumn, when the center of low pressure over Asia causes the winds to penetrate farther inland. Northwestern Europe has a rainfall well distributed throughout the year, with a slight excess in autumn and winter, due to the center of low pressure in the north Atlantic and the greater frequency of cyclonic storms. The rainfall gradient is steep in the British Isles and Norway, some places on the west coast having seven times as much rain as places one or two hundred miles to the east.

The high table-lands of central Asia are chiefly desert on account of the surrounding rim of mountains.

In southern South America the west winds bring ample rainfall to a narrow strip on the Pacific slope of the Andes, but it diminishes rapidly eastward, and the plains of Patagonia are arid.

During the southern summer (January) the southeast trades bring to southeast Africa and to Australia moisture, which is condensed by the highlands near the coast.

General Laws of Distribution. — In spite of the great irregularity of distribution of rainfall, four general laws may be observed.

(1) Rainfall decreases from the equator toward the poles.

(2) Rainfall is generally less in the interior of a continent than on the coasts.

(3) In trade-wind regions (between 35° south and 40° north) rainfall is greater on east coasts than on west. In antitrade-wind regions the reverse is true.

(4) Rainfall increases with altitude up to a certain elevation, which varies in different regions, and then diminishes. On mountain ranges the rainfall is greater on windward slopes. The position of high ranges is well marked on the rainfall map.

Although no known regions are absolutely rainless, about 20 per cent of the land surface has less than ten inches of rain per annum, and is consequently in a desert condition, while nearly 50 per cent has less than twenty inches, and is generally unfitted for agriculture without irrigation.

CHAPTER XXIX

WEATHER AND CLIMATE

Weather. — The conditions of the atmosphere at any given time constitute the weather. It includes pressure, temperature, humidity, state of the sky, precipitation, and direction and force of the wind. The most prominent characteristic of weather is its changeableness, the exact continuance of any given combination being hardly more than momentary. Weather changes are chiefly of three classes: (1) daily changes due to the rotation of the earth upon its axis, (2) yearly seasonal changes due to the revolution of the earth around the sun, and (3) irregular changes due to the passage of storms. The daily changes bring relatively warm days and cool nights, the yearly changes bring more or less decided variations of average daily and monthly temperature and rainfall, and the irregular changes bring alternations of fair and stormy weather. These various kinds of changes are of very different prominence and value in different parts of the earth.

Climate. — The average succession and distribution of weather conditions at any given place constitute the climate of that locality. The climate of a place can be determined only by taking into account a period of at least ten years. The factors of climate and the different methods of grouping them are very numerous. The most important factors are (1) the mean annual temperature, (2) the annual range of temperature, (3) the mean annual rainfall, and (4) the distribution of rainfall through the year.

The mean annual temperatures of New York and of London are nearly the same, but the range at New York is 40°, while at London it is only 20°. The rainfall of Portland, Ore., is forty-seven inches and of Portland, Maine, forty-two inches; but in Oregon two thirds of it falls in five winter months, while in Maine it is almost equally distributed through all the months.

Weather and climate are so closely related that they are studied to the best advantage together. The distribution of temperature and rainfall has been discussed in previous chapters, but it remains to consider their combinations with each other and with subordinate factors which determine the various climates of the globe.

Zones of temperature are well defined by isotherms as given on p. 295. Zones of rainfall bear close relation to the belts of pressure and prevailing winds, but their boundaries are vague and shifting, and each zone is far from presenting uniform conditions throughout. To map out zones which represent the distribution of the still more complex phenomena of climate is a difficult matter. The continents and oceans extending north and south cut across all zones and break them up into strongly contrasted portions. In discussing climatic zones sharp distinctions, definite boundaries, and uniform conditions must not be looked for.

The Trade or Constant Zone. — Figure 270 shows that the northern and southern limits of the swing of the isotherm of 70°, or the limits of hot summers, correspond quite closely with the tropical belts of high pressure and the limits of the trade winds. If the January isotherm of 30° is substituted for the July isotherm of 70° across North America and from central Europe to Japan, these boundaries will be near the parallels of 30° south and 40° north latitude, and mark out a zone of tolerably uniform climatic conditions. The zone bounded by these parallels is characterized as a whole by high and relatively uniform insolation amounting everywhere to more than 80 per cent of that at the equator, by prevailingly high temperatures

generally above 60°, by constant winds, by excessive rainfall, by an absence of strong seasonal contrasts, and by uniformity of weather conditions from day to day.

While the trade winds blow the daily changes are more prominent than any other, and the daily range of temperature may be greater than the yearly. The curves of temperature and pressure show their daily maximum and minimum with scarcely any variation from week to week. The sky is clear or partly cloudy in the daytime, and rain falls, if at all, in the latter part of the day. Cyclones rarely occur, but are extremely violent. The lowlands of the trade-wind belts are largely desert or semi-arid except on east coasts, and include the Sahara, Arabian, Australian, and South African deserts. The wind in these deserts is excessively dry and laden with dust. On account of the absence of cloud and moisture radiation is unchecked. The temperature at midday may rise to 110° or 120°, but at sunset the wind subsides and the air soon cools to temperatures not far above freezing.

The trade-wind belts are separated and modified by the belt of equatorial calms. As it swings back and forth it carries with it a calm, hot, moist air with abundant cloud and daily rainstorms. These conditions continue at any given place for two or three months, constituting the rainy season. Their most important results appear in the heavy rainfall and dense forests of equatorial Africa, equatorial South America, and the East Indian archipelago.

The Asiatic monsoon region is a peculiar and divergent offset from the trade-wind zone, subject to both extremes of wet and dry. In one season of the year the climate resembles that of the Sahara, and in the other that of the Amazon basin. In winter the weather is cool and dry, the northerly trade winds being occasionally interrupted by a mild cyclonic storm. The spring is dry and hot, but by June the southerly monsoon has become established and brings a copious rainfall which continues until October.

Transition Areas. — Certain limited areas along the borders of the trade-wind zone are included in that zone in summer and in the anti-

trade zone in winter. Among these are southern California, the coast lands of the Mediterranean, and southern Australia and Africa. They have a summer temperature between 65° and 80°, and a winter temperature between 50° and 60°, the annual range being less than 30°. They are too far from the equator to receive the equatorial rains and too near it to be visited by the cyclonic storms and cold waves of middle latitudes. In summer they have uninterrupted fair weather and in winter a light rainfall. Their climate is among the most enjoyable in the world, and in the northern hemisphere they have long been famous as health resorts.

The Southern Antitrade Zone. — Between the tropical belt of high pressure and the Antarctic circle the face of the earth is occupied by the sea, interrupted only by New Zealand and the narrow extremity of South America. This zone presents, therefore, in a high degree, the characteristic oceanic climate of middle latitudes. The westerly winds are almost as steady as the trades, but are much stronger. The ocean currents wheel perpetually with the winds around the polar center, and their circuit is joined in only two or three places by streams of air or water from the north. Cloud, fog, and storm are the rule at all seasons. The mean annual temperature is low and the daily and yearly ranges are small. The chief difference between the seasons is the greater frequency and strength of cyclonic storms in winter. There is neither summer nor winter, in the northern sense of the words, but an alternation, at intervals of two or three days, of more and less stormy weather which may bring rain or snow in any month of the year. The southern zone is truly *temperate* in that its climate is singularly free from extremes of any kind and uniform in its distribution over the whole zone. It is also truly variable in that weather changes are frequent although not of great magnitude. Here great variations of insolation are almost overcome by the equalizing effect of a large body of water.

The Northern Antitrade Zone. — The middle latitudes of the northern hemisphere are occupied by the largest land masses on the globe, and consequently possess a climate in strong contrast with that of the corresponding southern zone. The northern zone is truly *intemperate*, in that its climate is characterized by extremes of all the factors and by a want of uniformity in their distribution. Extremes

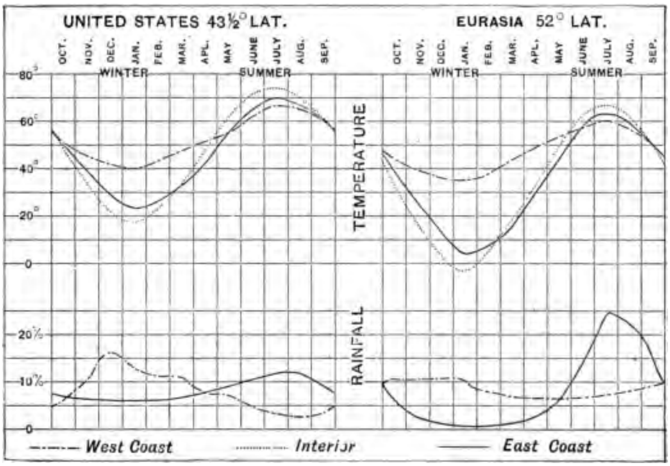


Fig. 300.

prevail through so large a part of the year that annual averages lose their value. The seasons of maximum and minimum temperature are separated by well-defined transition periods. The occurrence of four distinct seasons of nearly equal length is peculiar to this zone. Daily changes are most prominent in summer, and irregular cyclonic changes in winter. On account of the different heat relations of land and water (see p. 296), the isotherms over the land bend far southward in winter (see Fig. 268) and far northward in summer (see Fig. 269). Over the

oceans reverse bends are equally decided. This irregularity is intensified by a cold current on the west side of each ocean and a warm current on the east side. West coasts of the land are swept by winds from the ocean and have an oceanic climate. East coasts are swept by winds from the continents and have a climate similar to that of the continental interiors. Under the combined influence of these conditions the isotherms near either coast extend almost parallel with it, especially in winter, and the temperature varies more rapidly along east-west than along north-south lines. Another result is the great range of temperature in the interior of the land masses (see map, p. 299). The differences of climate between the west coasts and the interiors rival in magnitude those between the equator and the poles.

West Coast Climate. — On the western coasts of North America and Europe, in the antitrade zone, the climate is almost as equable as that of the trade wind belt and less stormy than that of the south temperate zone. The air is damp and more than half the days are cloudy. In winter there is an almost constant fog and drizzle of rain, with snow on the higher elevations. The winds are more northwesterly in summer and more southwesterly in winter. There is an excess of rainfall in winter. The winds from the ocean and the prevailing cloudiness combine to prevent great or sudden changes of temperature. The lines of equal annual range run parallel with the coast, the range slowly increasing northward from 20° to 40° in America and from 15° to 30° in Europe.

Eurasia. — On account of the strength and constancy of the southwest winds over the north Atlantic and the great mass of warm water driven by them in the Gulf Stream, the British Isles and Norway enjoy winters of unparalleled mildness for their latitude, and in strong contrast with the east coast of America on one side and the interior of Eurasia on the other. To the eastward there is a gradual change from these moist and temperate conditions to the dry steppes traversed by the Volga and Ural rivers, the arid plains of the Caspian and Aral depression, the bleak wastes of the Tarim and Gobi deserts, and the severity of east Siberian climate, where the lowest winter temperature and

the greatest annual range on the globe occur in the same province. The great ranges of temperature extend with some mitigation to the Pacific coast, where the winters are nearly as dry and cold as in the interior. The summers are cool and rainy, with a southeast monsoon.

North America. — The region of equable temperature and copious winter rains on the west coast of North America is confined to a narrow belt between the sea and the mountains. A day's journey by rail would carry the traveler from the mild climate of the coast to the parched and burning deserts of Nevada, or the frozen and almost equally dry plains of the Mackenzie basin. The interior of North America is second only to central Asia in the intemperate character of its climate. The isotherm of 60° swings from near the tropic in January almost to the Arctic circle in July, where the summers are long and warm enough to ripen wheat. Summer temperatures above 100° are common over a great part of the region, and the winter temperature falls in some places to −50°, the absolute range reaching 170° on the northern boundary of the United States. On the dry and elevated plateaus radiation is rapid and the daily range of temperature is very large. In summer violent local storms bring the greater part of the rainfall, and in winter the whole country from the Arctic Ocean to the Gulf states is liable to be flooded for a time with air below zero. North of latitude 50° the severity of these conditions extends to the Atlantic coast, but south of that parallel they are gradually mitigated toward the southeast.

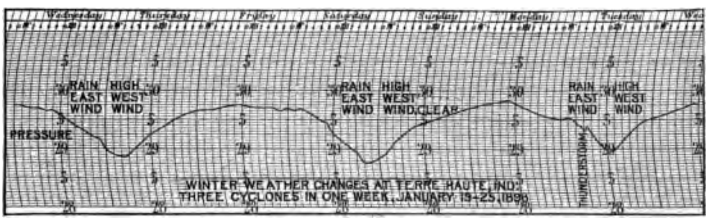


Fig. 301.

The eastern half of the United States lies open to the northwest winds from the interior center of cold and high pressure in winter, and to the regular southwest antitrades from the heated tropical center of Mexico and Arizona in summer. Cyclonic storms are more frequent than in any other part of the northern hemisphere, and while they impress upon the climate its peculiar variability, they carry moisture from the Gulf far inland. From October to May the weather may be

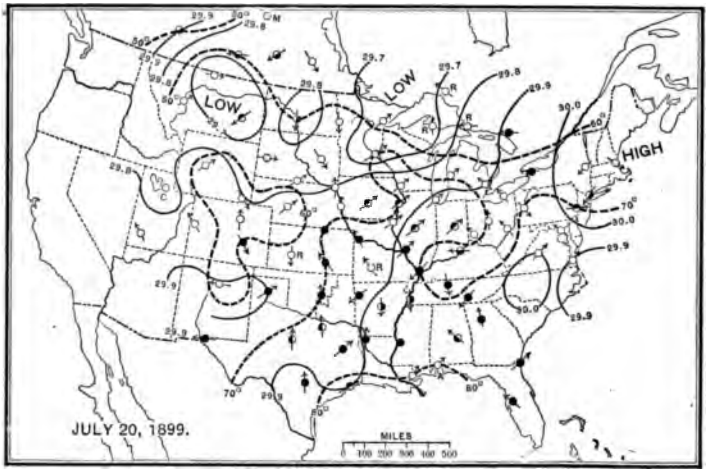


Fig. 302. — **A summer weather map.**

said to be controlled by a succession of cyclones and anticyclones, which alternate with each other on an average as often as twice a week, and bring each its characteristic type of weather.

In summer, cyclonic and anticyclonic conditions are much less frequent and pronounced, the distribution of pressure is often nearly uniform, and the isobars have no definite form or trend. The regular southwest antitrade wind blows with considerable strength, bringing a steady, moderately high pressure and clear, hot days. The nights are calm, clear, cool, and dewy. The barograph and thermograph curves show their daily maxima and minima with a regularity equal to that of the trade-wind region. These conditions may continue for weeks, but are liable to interruption by the passage of moderate cyclones.

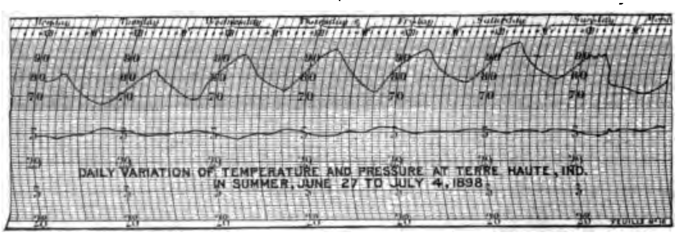


Fig. 303.

Summary of the Climate of the United States. — The United States may be divided into three regions which exhibit three strongly marked types of climate peculiar to a continental area in middle latitudes.

(1) *The Pacific coast* enjoys the mild, windward coast climate due to the prevailing winds from the ocean. The winters are warm and the summers cool except in the south-

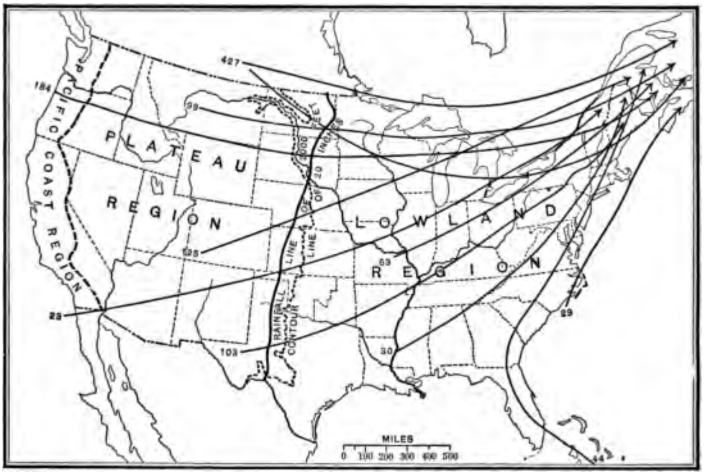


Fig. 304. — Cyclone paths and climatic regions of United States.

ern part. The wet season occurs in the winter and the dry season in summer. The rainfall increases rapidly from south to north.

(2) *The plateau region* is bounded on the west by the Pacific mountains and on the east by the rainfall line of 20 inches and the contour line of 2000 feet, both of which lie near the 100th meridian of west longitude. Its width is about 1500 miles, and its average elevation about 5000 feet. It has a truly continental climate intensified by its altitude. The winters are cold and the summers

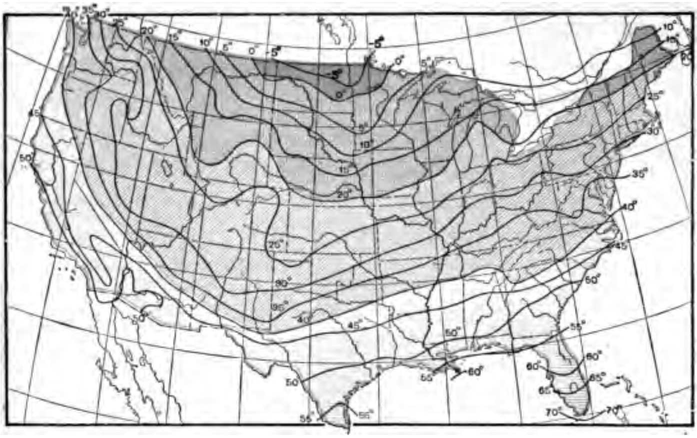


Fig. 305. — Average temperature for January in the United States. (After Greely.)

hot. In winter the cold is continuous and in summer the daily range of temperature is great. This region contains the coldest part of the United States, in Montana, and the hottest, in Arizona. Great and sudden changes of tem-

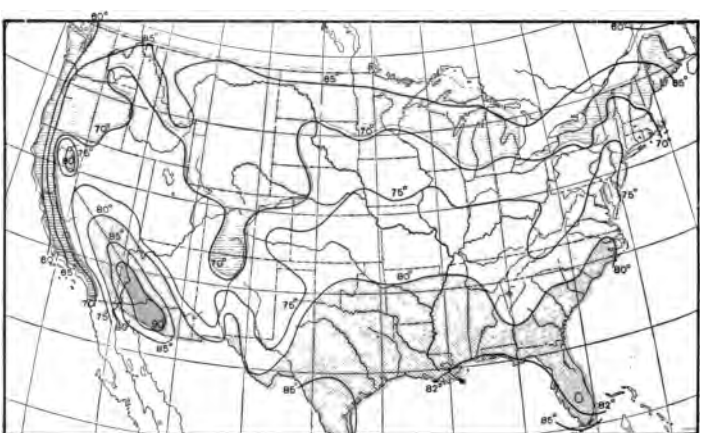


Fig. 306. — Average temperature for July in the United States. (After Greely.)

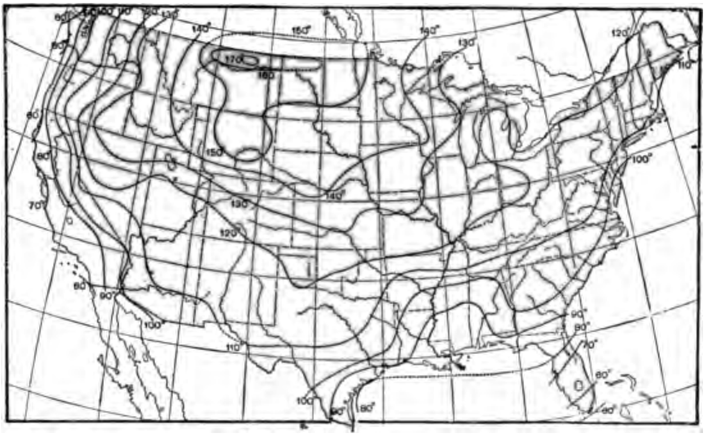


Fig. 307. — Absolute annual range of shade temperature in the United States.
(After Greely.)

perature are common. The rainfall is deficient, being almost everywhere too small for agriculture without irri-

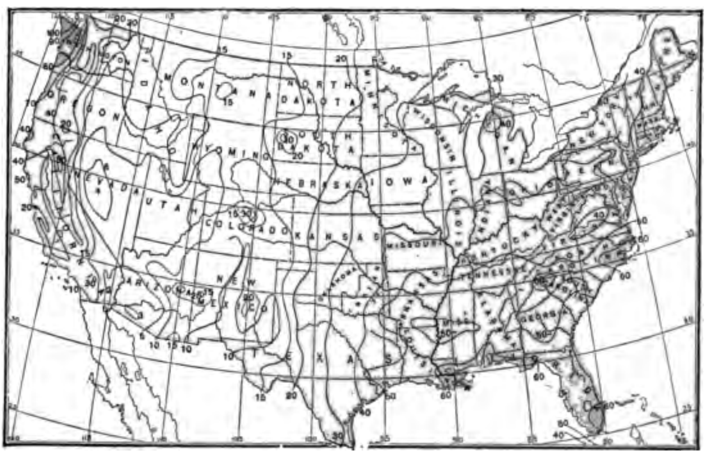


Fig. 308. — Average annual rainfall in the United States, in inches.
(U.S. Weather Bureau.)

gation. It increases from Arizona northward and from the Rocky Mountains eastward.

(3) *The lowland region* extends eastward from the contour line of 2000 feet and comprises about one half of the United States. Its climate is continental like that of the plateau region, but its extremes are mitigated by low altitude and the influence of the Great Lakes, Gulf of Mexico, and Atlantic Ocean. In the northwest the summers are hot and the winters cold, but these characteristics gradually change toward the southeast, the winters growing milder and shorter and the summers hotter and longer. The mean annual rainfall increases from northwest to southeast, and the annual range and variability of temperature decrease in the same direction.

The Polar Regions. — Owing to the prolonged continuance of daylight and darkness near the poles, the daily changes of weather are obliterated and merged with the seasonal. There are but two seasons, — a winter of nine or ten months, and a summer of two or three months, the change from one to the other being very abrupt. Although a large amount of insolation is received in summer, it is mostly expended in melting the accumulated ice and snow and does not raise the temperature much above freezing. Consequently the temperatures are persistently low. There is no warm season, and snow falls in every month of the year.

Humidity, cloudiness, and precipitation are greatest in summer. The precipitation is probably equivalent to less than ten inches of rainfall, but on account of slow melting and evaporation the snow accumulates and buries the land under glacial sheets upon which the short summers make little impression. Spells of stormy weather, probably cyclonic, are frequent at all seasons. Periods of calm are relatively warm in summer and intensely cold in winter. Low temperatures with calm, dry air are easily endured, but with high damp winds are exceedingly dangerous to beasts and men.

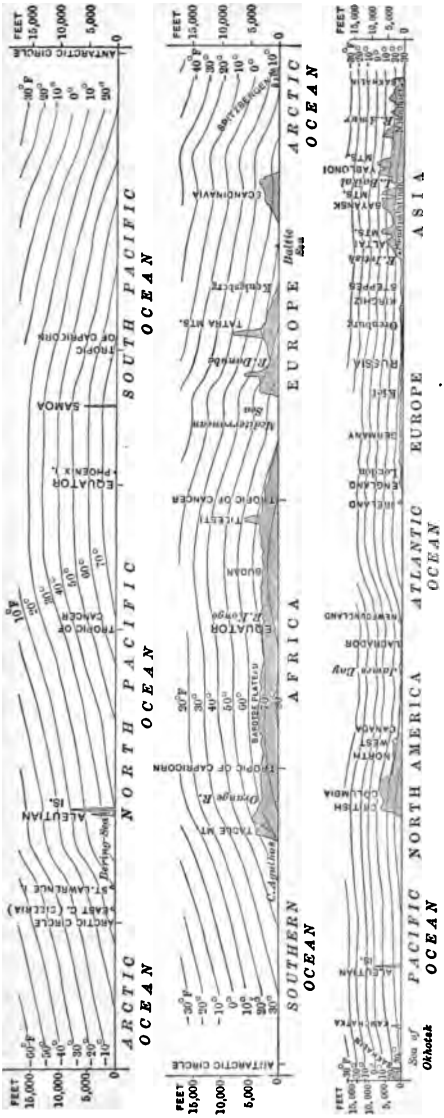


Fig. 309. — Vertical distribution of temperature.

Mountain Climate. — Mountains which rise from tropical lowlands to a height of four or five miles exhibit all the varieties of climate which exist between the equator and the poles, and with great regularity. As the altitude increases, the mean annual temperature falls and the yearly range increases. The annual rainfall increases to a certain height and then diminishes.

At high elevations the clearness and dryness of the air favor rapid heating and radiation; hence the differences of temperature between day and night and between sun and shade are great. Travelers suffer from the heat of the unclouded sun

upon their heads, while their feet in contact with snow or earth are in danger of freezing. The temperature by day on Mauna Kea, at a height of 13,850 feet, rises to 108° and at night sinks to 13°. The absolute yearly range in the shade on Mt. Ararat, 17,500 feet high, is from 63° to −40°.

In *free air* the changes with elevation are somewhat modified. The temperature falls on an average about 1° for each 300 feet of elevation, but the changes are irregular. Aeronauts find the air composed of distinct layers or currents between which the changes of temperature and humidity are rapid. Sometimes there is an *inversion* of temperatures, or a warmer layer overlying a colder. The following records of temperature have been obtained at various heights, chiefly from unmanned balloons: —

53,560 feet	−61.6° in shade		
49,200 "	−76° " "		
42,000 "	−96° " "		
38,700 "	−74° " "		
33,000 "	−58° " "		
31,500 "	−54° " "		−11° in sun.

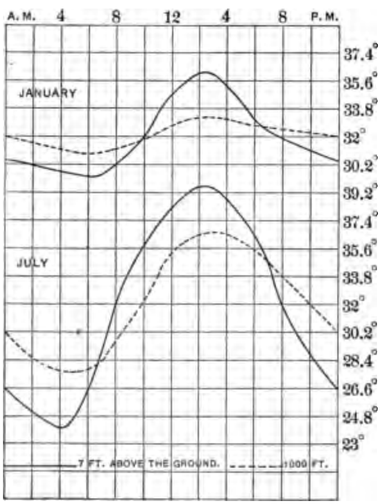


Fig. 310.

Fig. 309 shows the distribution of temperature in free air, by means of three sections of the atmosphere, with vertical isotherms.

The range of temperature in free air, both daily and seasonal, decreases rapidly with elevation. This is distinctly observable within a short distance above the earth, as shown in Fig. 310, which shows the average daily range at Paris near the surface and at the summit of the Eiffel Tower. Kite observations show that the daily range nearly disappears at a height of 3300 feet.

BOOK V. LIFE

CHAPTER XXX

PLANT GEOGRAPHY

Habitable Region. — The habitable region of the earth extends through a wide range of elevation and physical conditions, from the summits of the loftiest mountains to the profoundest depths of the sea. Condors have been seen soaring in the cold and rare atmosphere above the highest peaks of the Andes, and fishes have been dredged from the sea floor where they live in profound darkness and under a pressure of five tons of water to the square inch. Scarcely any portion of land, air, or water between these limits has been found entirely devoid of life. Living beings, both plants and animals, in their myriad forms, are everywhere dependent upon the physical conditions of temperature, humidity, air, and food supply. Their distribution is controlled by the most delicate adjustments and adaptations of structure, activity, and habit to those conditions, and can be explained only by a study of the relations existing between relief, climate, and life.

The Relations of Plants to Soil, Water, Air, and Climate. — The distribution of plants over the face of the earth depends upon a combination of all the great geographical conditions and upon the adaptation of the plant to those conditions as they exist in any given locality. Nearly all plants sustain certain constant relations to soil, air, and climate, and the endless variety of ways in which plants

have adjusted themselves to these relations has determined the diversity which we find in the *flora* or plant population of different regions.

Soil. — Most land plants have roots which ramify extensively through the soil, and thus furnish an anchorage which enables the plant to maintain a fixed position and in most cases an upright attitude. Plants also depend upon the soil for a supply of water and for materials which go to form the *ash* or incombustible parts. The best soils are mixtures of sand, clay, and humus.

Water. — Most plants absorb water from the soil through the roots. Water forms a large part of the raw material of plant food. It acts also as a circulating fluid which brings in and transports other materials to all parts of the plant, somewhat as the blood acts in the animal body. The presence of water in the plant cells keeps the stems and leaves stiff and turgid. As soon as it evaporates too rapidly, the plant wilts.

Air. — The chief supply of raw materials for plant food is derived from the air. Roughly speaking, the combustible portion of the plant, or about 75 per cent of its weight when dry, is built out of materials supplied from the air.

Light. — Green plants only are able to combine the elements of air, water, and soil, and to manufacture them into *food.* This process is carried on in the leaves and through the agency of sunlight. It can not take place in the dark. The air enters the mouths or pores which are very numerous on the under side of the leaf. The working cells on the upper side of the leaf contain green bodies which are able to break up the carbon dioxide of the air into its elements, carbon and oxygen. The carbon is combined with water to form starch, sugar, and other *organic* products, while the oxygen is given off as waste

matter. Thus the green cells of plants act as food factories, which are run by the power of sunlight.

Temperature. — For every plant there is a certain range of temperature within which it is able to work. The extreme range of the plant kingdom is from about 32° to 122° F. As a rule, any plant will flourish and be vigorous in proportion to the duration and height of the temperature within the range to which it is adapted.

The Geographical Distribution of Plants; Control by Temperature. — The most important condition which controls the distribution of plants is temperature. While the energy necessary for plant growth is supplied by sunlight rather than by heat, a proper temperature is one of the conditions essential for the accomplishment of all the processes of plant life. Hence temperature marks out broad zones, within which certain plants *may* thrive if other conditions permit, but outside of which they can not exist. Humidity and other secondary conditions determine the presence or absence of particular species of plants in particular localities within these zones.

The distance to which any species of plant may extend toward the poles, up a mountain side, or into any relatively cold region, depends upon the length and average temperature of the growing season. Corn requires a higher temperature and a longer season to mature than wheat; hence it can not be raised in as high latitudes as wheat. Sugar cane requires a still higher temperature and longer season than corn; hence it is restricted to regions nearer the equator. *The distance to which any species of plant may extend toward the equator, or into any relatively hot region, depends upon the average temperature of a period of about six weeks at the hottest time of the year.* Cotton and sugar cane will endure without injury a higher temperature prolonged for six weeks than wheat; hence they can be raised in much warmer climates than wheat.

Plant Zones. — The plant zones, as determined by temperature in North America, with some of their characteristic forms, are as follows: —

Fig 311 - Polar limit of trees, northern Russia

F g 312. · Coniferous forest, near the timber line, Colorado.

(1) **Polar** (Fig. 311). — Lichens, mosses, poppy, saxifrages, gentians, and willows, all dwarfed, tufted, and stunted.

(2) **Cold Temperate** (Fig. 312). — Coniferous forests; in the north, spruce and fir; in the south, pine, hemlock, cedar, redwood, sequoia.

Fig. 313. — Mixed forest, North Carolina.

Fig. 314. — Tropical forest, Mexico.

(3) **Warm Temperate** (Fig. 313). — Deciduous forests; in the north, beech, birch, sugar maple, dogwood; in the south, oak, hickory, chestnut, walnut, sycamore, sassafras, tuliptree, hackberry, sweet gum.

(4) **Tropical** (Fig. 314).—Broad-leaved evergreens, long-leaf

pine, magnolia, live oak, cypress, tupelo, palmetto, palm, mahogany, mangrove, yucca, cactus, agave.

(5) **Equatorial** (Fig. 315). — Forests characterized by a large number of species, the great height of the trees, and the number of climbing plants and air plants.

Fig. 315. — Equatorial forest, Mexico.

Control by Humidity. — Within the zones of temperature the distribution of species and groups of plants is determined almost entirely by water supply. According to the amount of water which they require, plants may be divided into three great classes: (1) water plants, (2) drouth plants, and (3) intermediate plants. These classes are again divided into numerous groups or plant *societies*, the members of which differ widely as individuals, but are so adapted to similar conditions and to one another that they are commonly found growing together without serious interference among themselves.

Water Plants. — A large class of plants flourish only in water or in very wet soil. (1) Floating or submerged plants are characterized by thin walls through which water is absorbed by all parts of the plant. Roots being unnecessary are absent or used for anchorage only. The plant is supported by the water, and has no need of stiffness; hence it is soft and flexible. Numerous species of sea-

Fig. 316. — Plants with floating leaves.

Fig. 317. Reed swamp.

weed belong to this class, some of which attain such dimensions as to rival the largest of land plants. Bladderworts and duckweeds are common floating plants in fresh-water lakes and ponds. (2) Many plants are rooted to the soil, but have submerged or floating leaves, like the pondweeds and water lilies. The submerged leaves are commonly narrow and threadlike, and the floating ones very broad (Fig. 316). (3) Swamp or marsh plants are rooted in water or very wet soil, while their stems and leaves are exposed to the air.

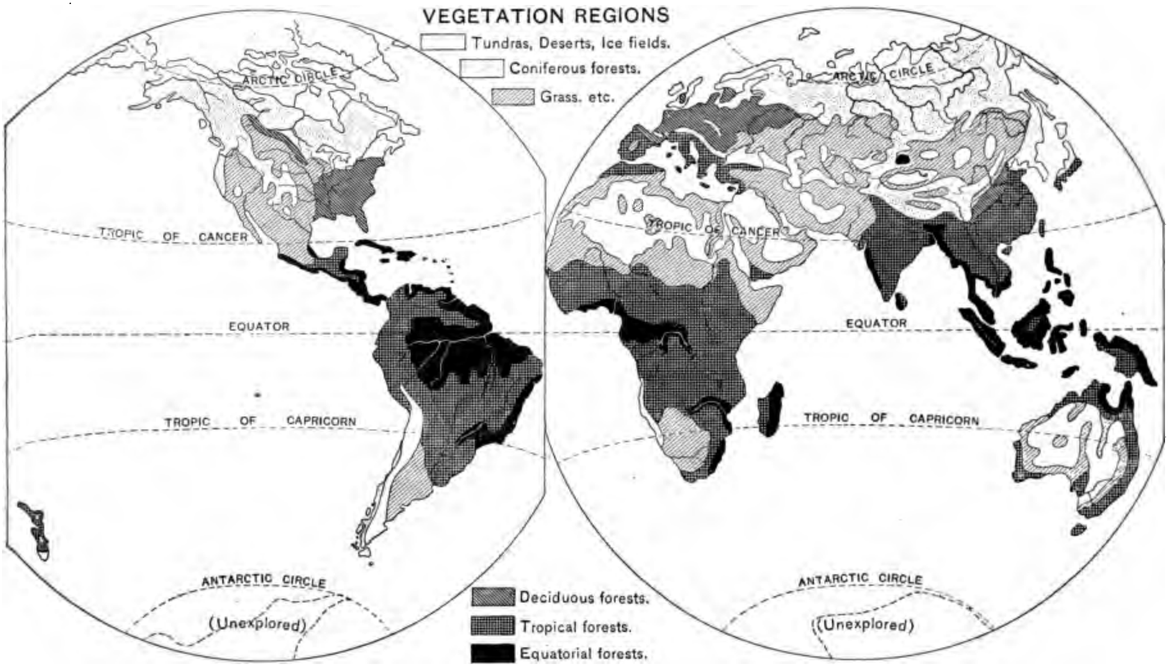
Fig. 318. – Cypress swamp.

Fig. 319. — The giant cactus, Arizona.

Many societies of them are common in temperate climates: among them may be found cat-tail flags, reed grass, sedges, willows, alders, tamarack, and cypress (Figs. 317, 318).

Drouth Plants are adapted to thrive in a dry soil and climate. They generally have an extensive root system in proportion to the size of the plant, a small leaf surface, and a thickened epidermis. Many plants survive regular periods of drouth by the disappearance of root, stem, and leaves, and the reduction of the individual plant to seeds, bulbs, or tubers. The shedding of leaves is a provision against destruction by the dry as well as the cold season. The reduction of the leaves to threads or needles, as in the pine and other species of coniferous trees, and the total absence of leaves, as in the cactus, are efficient means of withstanding drouth. The perfection of these adaptations is probably found in the melon cactus, in which the whole plant is reduced to a spiny, thick-skinned, globular mass.

Intermediate Plants. — This class of plants adapted to a medium supply of water comprises about 80 per cent of all known forms and constitutes the more common vegetation of temperate regions. The principal societies include a great number of species and individuals, but are easily recognizable. (1) Arctic-Alpine carpets are found in the polar regions and at high elevations where the low temperature and short season prevent tall growth. The northern borders of Eurasia and North America are occupied by the *tundras*, where the ground is perpetually frozen to a great depth, and in the short summer thaws out only on the surface. These are covered chiefly with mosses and lichens. In more favorable localities, where higher plants occur, the vegetation has a remarkably fresh and green appearance, the growth is very rapid, and the flowers are of large size and bright colors. The shrubby plants spread out close to the ground and the whole forms a low, soft, dense, brilliant covering, appropriately called a carpet. (2) Prairies, in the central United States, are extensive plains having a deep, rich, humus soil with a moderate supply of water. They are exposed to irregular drouths and to dry, hot winds unfavorable to tree growth. They are covered with a luxuriant growth of grass and herbs, among which sunflowers, golden rods, and compass plants are conspicuous. Some timber occurs along the streams. Similar tracts are called *steppes* in southern Eurasia, and *llanos* and *pampas* in South America. (3) Deciduous forests consist of trees that shed their leaves. A comparison of the maps on pp. 328 and 358 shows that forests are characteristic of



VEGETATION REGIONS
Tundras, Deserts, Ice fields.
Coniferous forests.
Grass. etc.
Deciduous forests.
Tropical forests.
Equatorial forests.
ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ANTARCTIC CIRCLE
(Unexplored)
ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ANTARCTIC CIRCLE
(Unexplored)

regions of large rainfall. Practically no forests occur in regions of less than twenty inches of rainfall except the coniferous forests in regions of low temperature where evaporation is slow. In deciduous forests the thin, broad, horizontal leaves give the largest possible surface exposure to air and light and have great working power while the growing season lasts. (4) Broad-leaved evergreen forests occur in the trade-wind belts of heavy rainfall, high temperature, and rich soil, and are especially luxuriant in the Amazon basin. The new leaves continually appear before the old ones are shed. The growth is very dense in layer above layer, mosses, herbs, shrubs, and trees, and all covered and overrun by air plants and climbing plants. The trees are tall, straight, and without limbs except at the very top. The number of species is astonishing. On 60 square miles in Brazil 3000 species of plants, including 400 species of trees, have been counted.

Control of Distribution by Methods of Migration. — While individual plants are usually anchored to one spot, plant species migrate as truly as birds, and some have traveled around the world. If the conditions are favorable, plants are continually spreading so that each generation occupies more territory than the preceding.

The methods of plant migration are very numerous. (1) The seeds of many plants are scattered by the wind, and many seeds are provided with wings, hairs, or down for this purpose. The maple, poplar, cottonwood, sycamore, dandelion, milkweed, and thistle are familiar examples of plants whose seeds are specially adapted for transportation by the wind. Hence they travel more rapidly and establish themselves in a new field more quickly than heavy-seeded plants. (2) Many seeds are provided with hooks by which they attach themselves to animals and the clothing of men. These include what are popularly known as ticks, stickers, beggar's lice, burdocks, and cockleburs, and many other varieties. (3) The seeds of edible fruits and berries are carried away by birds and other animals. (4) Some plants, like the touch-me-not, have explosive seed pods which burst when ripe and throw the seeds to some distance. (5) Seeds may be floated by rivers and ocean currents to great distances. Trees are apt to extend farther into new territory along streams, and the shell of the cocoanut enables it to survive a long voyage in salt water. (6) Man is, often unintentionally, a most efficient disseminator of plants. Besides the various cultivated plants

which he has carried to all parts of the world, many undesirable ones have accompanied him. Most of our common weeds are robust and vigorous foreign plants which have extended themselves along lines of human travel, as the Russian thistle, French corn cockle, and Italian mustard.

Control of Distribution by Barriers. — Migration is not unlimited, because there are barriers which most plants can not cross. The most efficient are oceans, mountain ranges, deserts, and regions already occupied by luxuriant vegetation. The plants of North America and Eurasia are much more alike than those of South America and Africa, because they have not been separated by such wide ocean barriers. The plants of Florida and Canada are more alike than those of Florida and Cuba, because the Florida strait, swept by the Gulf Stream, is an effectual barrier between these two regions.

The Struggle for Existence. — It requires but slight observation to see that in nature very few plants find the best conditions for their growth. The difference between a neglected roadside and a well-kept garden illustrates this. By the roadside a multitude of grasses, weeds, and bushes struggle with one another for possession of the ground. The weaker are finally crowded out by the stronger, but not one has all the light, air, water, and soil to itself. In the garden a few selected plants are given all the room they need, and are fed, watered, and protected, while rivals and enemies are carefully destroyed. In nature each plant must maintain itself, as best it can, against the rivalry of other individuals of the same kind, against plants of other kinds which are adapted to similar conditions, and against numerous insects, birds, and burrowing or grazing animals. Every blade of grass in the meadow and every tree in the forest is more or less interfered with by its neighbors and gets only such a share of light, air, and water as it is able

to seize in spite of them. Most plants multiply so rapidly that all their offspring could not possibly find room on the earth. A single tobacco plant produces 360,000 seeds in a year. If every seed produced a plant, in a few years the whole surface of the dry land would be covered with them.

Changes of Environment.— Not only does the natural spread of plants carry them into new conditions, but the conditions in any region or locality are subject to change. Lakes and swamps dry up, are filled with sediment, or are drained. Areas usually dry are sometimes flooded. The growth of tall and rank vegetation cuts off the supply of light for the lower forms. The clearing of forests subjects the shade-loving plants which grew beneath them to new trials. Widespread changes of climate have sometimes involved a large part of a continent, as that from wet to dry in the Great Basin and from warm to cold during the glacial period in North America and Europe. If such changes are rapid, all or most of the plants are destroyed; if they are sufficiently slow, the species of plants may survive by migration to other regions.

Adaptation. — Whether plants remain at home or undertake migration, they are subjected to a constant struggle for existence, by the competition of their neighbors and by the pressure of new conditions. They are all subject to the law of *heredity*, by which new plants resemble in a general way the parent stock. They are also subject to the law of *variation*, by which every individual plant differs more or less from all others. Among all the millions of slight variations some are advantageous to the plant and some are the reverse. Those plants which are endowed with some advantage of form, structure, or habit, are, to that extent, better able to compete with their fellows, and with changed conditions. Such plants are

more likely to survive, to mature seed, and to produce numerous offspring, to which they transmit their own peculiarities. This goes on from generation to generation, advantageous peculiarities become permanent, and the successive generations become so different from their ancestors and relatives as to constitute new varieties and species. This process is called *adaptation* or the *survival of the fittest*, which means only that no two plants are exactly alike, and that some, being better fitted to contend with unfavorable conditions, necessarily survive and multiply faster than those more poorly equipped. By such processes the hundreds of thousands of species of plants known to exist in the world have developed from a few original forms. Thousands of species which once flourished have become extinct, while new varieties and species are still being produced.

Influence of Past History. — From all these considerations it is evident that the distribution of plants in any region has been determined not only by the present conditions of the region, but also by its past history. The greatest contrast exists between the plants of the northern hemisphere and those of the southern. Very few species are found in both except those which have been carried by man. The equatorial region has been the cradle and nursery of plant life, in which species have originated, and from which they have migrated north and south. The ground there being fully occupied, the luxuriant vegetation forms a barrier practically impassable from one side to the other. The variety of vegetation in any country depends largely upon its age, that is, the time which has passed since it was last covered by water or ice.

Brazil is a very old country, and the number of species growing there is very large. Northern Europe is a very young country. The

ice sheet of the glacial period swept it clean of its pre-glacial flora, and there has not been time since for many species to establish themselves; their present number is not half that in Brazil. In North America the glacial period forced northern plants southward, where many still remain. The majority of plants in the region of glacial drift are recent immigrants. Some, like the willows and maples, betray their northern origin by hastening to produce their flowers and seed in early spring; others, like the asters and golden rods, show their southern origin by taking the whole summer to mature, and producing flowers and seeds only in the autumn. The north-south mountain ranges of North America have not been barriers to migration so much as roads along which plants have traveled southward, and then descended into the plains. The east-west mountain ranges of Europe have been effectual barriers. During the glacial period few northern plants were able to escape destruction by migrating over the mountains, and since its close few have been able to reach northern Europe from the south; hence that region has fewer species than North America.

CHAPTER XXXI

ANIMAL GEOGRAPHY

Relations of Animals to Climate and Plants. — The tissues of the animal body are able to maintain life and activity only under definite conditions of temperature; but most animals have the power to maintain within themselves the proper temperature, whether it be higher or lower than that of the surrounding medium. Hence they are less dependent upon climatic conditions than plants. Animals require water and a constant supply of oxygen from the air. The most important relation which animals sustain to other geographical conditions is their dependence upon plants for food. No animal has the ability to live upon mineral food alone, or to manufacture organic food from the raw materials of earth, water, and air. This can be done only by the green cells of plants, and upon such organic food all animal life is absolutely dependent; for flesh-eating animals feed on plant-eating animals. Thus the distribution of animals is influenced either directly or indirectly by the same conditions as that of plants. The laws of heredity and variation prevail among animals, and they are subject to the rivalry and competition of their neighbors to a degree proportional to their complex organization and wide range of activity. The struggle for existence is severe and destructive to untold millions of individuals, and only those survive which are able to develop some peculiar power or resource which gives them an advantage over their fellows. To procure food and to defend itself and its offspring from enemies, are the chief *problems* which every animal must face.

Origin and Distribution of Animals. — The millions of animal forms which now people the earth have descended from a few parent forms which were probably unlike any now in existence. Every animal has its origin far back in the geologic past. In many cases a long series of fossil forms are known which connect living animals with their remote ancestors. The line of descent of the modern horse has been traced back through ancestral forms, more and more unlike a horse, to a five-toed animal of the size of a fox. To account for the present distribution of any species of animal, it is necessary to consider two questions: where did it originate? and how did it reach its present home? The first question is answered, if at all, by a study of the rocks which contain the fossil remains of extinct forms, and a discovery of the locality and period in which the animal in question or its ancestors first appeared. The second question is answered, if at all, by a study of the methods of migration which the animal possesses, and of the barriers or bridges which have existed between its birthplace and its present home.

Migration of Animals. — Animals have much greater facilities for migration than plants, yet they are restricted in their wanderings by the same great barriers of ocean, desert, and mountain. The effect of barriers and the varying ability of different animals to surmount them may be illustrated by a case which might occur among the domestic animals of a farm. Suppose a farmer has four fields arranged as in Fig. 320. B is separated from A by a wide, close hedge; C by a high, strong fence; D by a pond. If the animals named are placed in A, which would be likely to get into each of the other fields first? The swine might work through the hedge into B, the ducks would quickly swim across the pond to D, followed perhaps by the swine,

cattle, and horses. Some horses might jump the fence into C, and some fowls would be able to fly over it. The sheep would remain in A, while the pigeons would be unrestrained by any of the barriers. The actual problem of distribution is complicated by the fact that as animals migrate into new conditions of climate and food supply, and meet new rivals and enemies, those which survive usually do so by gradual adaptation to their changed environment, and thus through thousands of generations become more and more unlike their ancestors and one another.

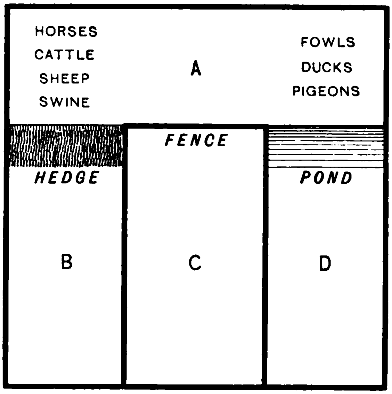


Fig 320.

Areas of Distribution. — Each species of animal occupies a certain territory which is called its area of distribution. The areas of distribution of different species usually overlap; when the boundaries are sharply defined, they are formed by natural barriers, such as a river, strait, mountain, forest, or treeless plain.

Of all animals birds are the most widely distributed. The fishhawk and barn owl range over nearly the whole world. Crows, swallows, doves, grouse, hawks, owls, snipe, herons, ducks, gulls, petrels, and pelicans occur in all parts of the world. Humming birds range from Cape Horn to Alaska, and from sea level to the snow line. Among mammals the only family with great powers of flight, the bats, have as wide a distribution as birds. Many similar cases are found among butterflies and beetles. The Bengal tiger ranges from the hot, damp jungles of southern India over the loftiest mountains on the globe to the dry steppes of

Siberia, yet he has never been able to cross the forty miles of water between India and Ceylon. Equally remarkable examples are found of species which are restricted to a single small area. The gorilla is confined to the equatorial forests of west Africa, the aye-aye to Madagascar, and a peculiar lizard to one or two small islands off the coast of New Zealand. One species of humming bird has been found only in the crater of Chimborazo, and a certain species of fish in a single small lake in Scotland. In the Hawaiian Islands each valley, often each side of a valley, and sometimes each ridge and peak, has its own peculiar species of snails. Fresh-water fishes and land snails generally have the smallest range. Many instances of restricted range may be explained by the fact that the species is either a new one which has not yet had time to spread, or an old one which once occupied a wider area and is now nearly extinct.

The Zoölogical Realms and Regions. — As shown by Fig. 321, the land surface of the earth is divided according to its

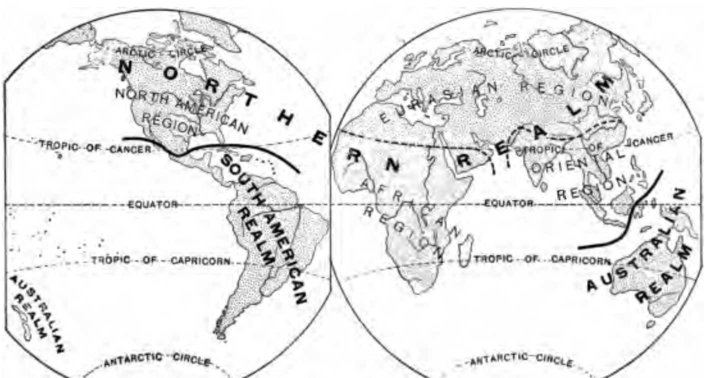


Fig. 321. — Animal realms and regions.

living inhabitants into three realms, which are very unequal in area, but differ widely in their flora and fauna. They are: (1) the Australian Realm, comprising Australia, Tasmania, New Zealand, New Guinea, and other neighboring islands; (2) the South American Realm, comprising South

and Central America and the West Indies; and (3) the Northern Realm, comprising Eurasia, Africa, and most of North America. It is to be noticed that the southern continents, which are widely separated from one another by the oceans, belong each to a different realm, while the northern continents, which form an almost continuous land mass, are all in the same realm.

The Australian Realm presents the most peculiar assemblage of plants and animals in the world. The great body of it is desert or semi-arid and unfavorable for the development of the higher forms of life.

Its mammals, with few exceptions, belong to two small and unique groups, the egg layers (*monotremes*) and the pouched animals (*marsupials*). The former is represented by the duckbill, an aquatic, burrowing animal of the general form, size, and fur of a muskrat, but having webbed feet and a broad bill like a duck. It lays eggs and suckles its young. The pouched animals, represented by the kangaroo, have a pouch, formed by a fold of the skin of the abdomen, in which the young are carried for some time after birth. In form and habits they are very diversified, some resembling wolves, others weasels, squirrels, rabbits, moles, rats, and mice. The largest is the kangaroo, which, when sitting upon its hind legs and powerful tail, is as tall as a man. The only pouched animals found outside of Australia are the opossums of America. The only other Australian mammals are rats, mice, bats, and a single species each of pig and dog. The birds are almost as peculiar as the mammals; they include paradise birds, lyre birds, cockatoos, many species of parrots and pigeons, the large and almost wingless kiwis, emus, and cassowaries, and the brush turkeys, which build large mounds of leaves and brush wherein their eggs are laid and hatched by the heat produced as the pile ferments.

The plant life of the Australian Realm is as odd as its animals. Many of the trees are leafless or have grasslike leaves. The gigantic eucalyptus or gum trees have leaves which stand with their edges to the sky. Many new plants and animals have been introduced by man.

The animals of New Zealand are so remarkable as to distinguish it from the rest of the Australian Realm. Although a large continental island, it has no mammals except two kinds of bats and one species of

Fig. 322. — Australian animals.

rat. It is characterized by several species of gigantic wingless or flightless birds, now nearly or quite extinct. Their nearest relatives are found in the ostrich of Africa and the rhea of South America.

The fossil remains of the earliest ancestors of the pouched animals are found in Eurasia, and it is practically certain that they migrated thence to Australia at a very remote period when that continent had a land connection with Asia. By a subsidence of the land bridge they were cut off from the rest of the world, and the access of higher and more vigorous forms was prevented. The absence of large birds or beasts of prey relieved them from their most formidable enemies, and they have been permitted to multiply in peace and safety. Australia is a sort of biological museum in which forms which long ago flourished and were destroyed on other continents have been entrapped and preserved. The realm is separated from Asia by a series of deep straits called "Wallace's line." Between the islands of Bali and Lombok the strait is only fifteen miles wide, yet a large proportion of the animals, including even half of the birds, are different upon opposite sides of it.

The South American Realm is bounded upon all sides by wide and deep oceans except on the north, where it is connected with the Northern Realm. It is a country of extensive tropical forests and open grassy plains, admirably adapted for the support of abundant life. The forests are the most extensive and luxuriant in the world, covering the low plains and extending up the mountain sides to a height of 8000 or 9000 feet. The open grass lands of Venezuela and northern Brazil alternate with the forest, while the pampas of the south are a vast sea of grass. As might be expected, this realm is surpassingly rich in nearly all forms of life.

It contains representatives of more than half of all the vertebrate families in the world, and more than one fourth of these families occur nowhere else. Its most characteristic animals are the *edentates*, toothless and armored forms represented by the armadillo, an animal of the size and habits of a small pig, but covered with bony plates. When attacked it rolls itself into a ball which is completely covered by the shell. In former times similar animals of gigantic size, having a shell six or eight feet in diameter, were numerous. To the same group belong the sloths and anteaters. In the hot forest regions are the prehensile-tailed monkeys and marmosets, both peculiar to this realm. There are a few deer, but no other hoofed animals except the peccary, allied to the pig, and the tapir, allied to the elephant. The *rodents*, or gnawers, are represented by the chinchilla, the guinea pig, and the capybara, the largest of its order. Vampire and leaf-nosed bats are numerous. The camel tribe is represented by four peculiar species, the llama of the high Andes, the only native beast of burden; and the alpaca, vicuña, and guanaco, valuable for their wool. The principal beasts of prey are the puma, or panther, and the fierce and powerful jaguar, which successfully attacks horses and oxen. In birds this realm is even richer than in mammals, and five sixths of them do not occur elsewhere. There are nearly 400 species of humming birds. Other characteristic birds are sugar birds, tanagers, chatterers, tree creepers, parrots, toucans, curassows, trumpeters, umbrella birds, sun bitterns; condors, the largest of flying birds; and the rhea, or American ostrich. Among reptiles are the boa constrictor and anaconda, the largest of

serpents; turtles, alligators, crocodiles, and numerous lizards. In fresh-water fishes and insects the realm is rich almost beyond description.

One of the strangest peculiarities of the realm is the fact that although the pampas form a paradise for grazing animals, there are no native cattle, horses, sheep, goats, or antelopes, the vast herds which now exist there having been introduced by man from Europe.

Among the thousands of native plants peculiar to the realm are many palms, the milk or cow tree, melon tree, custard apple, evergreen

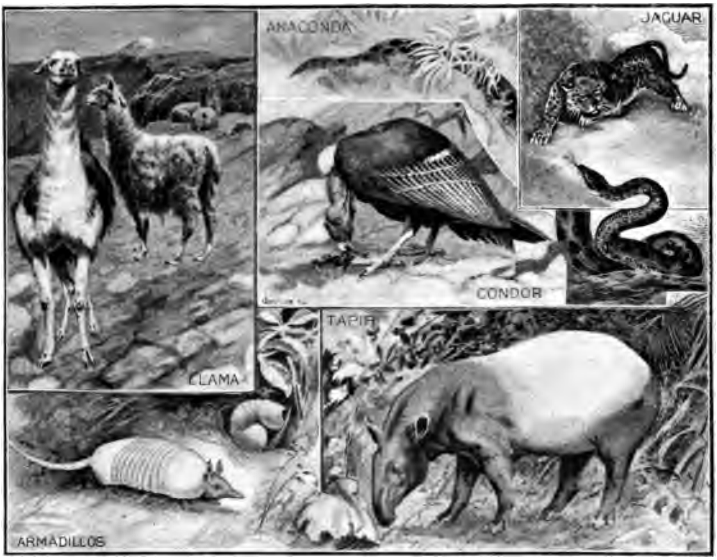


Fig. 323. — South American animals.

beech, Brazil nut, araucaria, Paraguay tea, Victoria regia, pampas grass, and those which yield logwood, quinine, guava, chocolate, rubber, spices, and varnishes. The potato, tobacco, cayenne pepper and Indian corn probably originated in South America.

The peculiarities of South American forms of life point to long periods during which the continent was separated from the rest of the world, and to a gradual increase in land area and in diversity of relief and climate. These conditions were favorable to the development of species in extraordinary numbers and variety. The isolation was inter-

rupted at various times by temporary land connection with North America, which furnished opportunities for invasion by many northern forms.

The Northern Realm, comprising four fifths of the land surface of the globe, is characterized by a general similarity of plant and animal forms, as contrasted with those of the Australian and South American realms, but it is divided into several more or less distinct regions.

The African Region, including Africa south of the Sahara, and the island of Madagascar, is not far behind South America in number, variety, and peculiarity of species. In the east it is a moderately elevated plateau with a hot and rather dry climate, occupied by open grassy plains and hills with patches of forest. In the west the dense forest resembles that of South America. In the south semi-arid and desert conditions prevail.

In this life region are found the manlike, tailless apes, the gorilla and chimpanzee; baboons and lemurs; the elephant, rhinoceros, and hippopotamus, the largest of land animals; the giraffe, zebra, quagga, lion, leopard, jackal, hyena, and about eighty species of antelopes. It is equally remarkable for the absence of tigers, wolves, foxes, bears, wild oxen, deer, sheep, goats, camels, moles, and true pigs. It abounds in eagles, vultures, and guinea fowls, and has the peculiar serpent-eating secretary bird and the ostrich. Serpents are numerous, including vipers and puff adders. It is also the home of the chameleon. Two thirds of its mammals and three fifths of its birds do not occur elsewhere.

Madagascar bears the same relation to Africa that New Zealand does to Australia, but possesses a richer and more remarkable fauna than New Zealand. It is characterized especially by lemurs, bats, civet cats. and a great variety of birds, but most of the groups abundant in Africa are wholly wanting.

The plants of the African Region include the baobab, cotton tree, oil, wine, and screw palms, banana, plantain, yam, manioc, mangrove, breadfruit, coffee, aloe, tree spurges and heaths, prickly acacias, lilies, orchids, pelargoniums, and the strange welwitschia.

The African Region has for a long period been separated from northern lands by the Sahara, which is almost as efficient a barrier to migra-

Fig. 324. – African animals.

tion as a sea of equal width. In early times South Africa and Madagascar were united with each other, and possibly with India, by a land area in the present Indian Ocean. Later, Africa was separated from Madagascar and united with Eurasia so as to permit an influx of higher and larger animals from the east and north.

The Oriental Region includes Asia south of the Himalaya and Sulaiman mountains, together with neighboring islands. Its area is small, but its surface is very diversified. The mountains form a less efficient barrier than the sea or desert; consequently this region is less peculiar than the African, with which it has many features in common.

It is remarkable for its orangs, chimpanzees, and an abundance of monkeys, gibbons, and lemurs. It is especially rich in the cat tribe, of which the tiger is easily chief, with the lion, leopard, and panther not much inferior. There are thirty species of bats, and fifty each of mice and squirrels. The elephant, rhinoceros, bear, tapir, wild boar, and wild cattle abound. Of birds it has contributed the pea fowl, pheasant, and jungle cock, from which the common domestic fowl is derived. Tailor birds, thrushes, woodpeckers, cuckoos, and hornbills are com-

Fig. 325. — Oriental animals.

mon. Among reptiles, crocodiles and venomous serpents are very abundant. About half of the mammals and birds are peculiar. In number, variety, and beauty of birds, butterflies, and beetles this region is unrivaled.

Among its most useful plants are the bamboo, banyan, sago and areca palms, camphor tree, teak, gutta-percha tree, balsam, incense, cinnamon, nutmeg, pepper, clove, and mangosteen.

The ancestors of most of the characteristic forms of the Oriental Region lived in Europe and northern Asia at a time when a tropical *climate extended* far toward the pole; the lofty plateaus and mountains

of central Asia had not yet been uplifted, and substantially one fauna ranged over the whole of Eurasia. The elevation of the highlands, the northward extension of the Siberian plain, and the change to a more severe climate will account for the diversity and division now found in that continent.

Fig. 326. — Eurasian animals.

The Eurasian Region contains the whole of Europe, Africa north of the Sahara, and the whole of Asia except the Oriental Region and the southern part of Arabia. Extending from Iceland on the west to Japan on the east,

it comprises all the north temperate portions of the eastern hemisphere, yet the majority of its plants and animals are identical throughout. It contains very few peculiar forms, but has been a center of development for a large number which have migrated from it to other regions. In comparatively recent times, the elephant, hippopotamus, rhinoceros, and lion were as abundant in Europe as they now are in Africa, while the mammoth or hairy elephant of Siberia, recently extinct, is thought to be the immediate ancestor of the Indian elephant.

Almost the entire family of moles is confined to this region, as is also the badger. Of hoofed animals the camels have their native home in central and western Asia. There are many peculiar species of lynxes, badgers, deer, oxen, sheep, goats, and antelopes, among them the yak of Tibet and the chamois of the Alps. There are also peculiar forms of rodents. Wild horses occur in central Asia, several species of wild cattle in Europe, and reindeer in the north. Elks, bears, and wolves are widely distributed. Numerous species of birds are characteristic, among which are crows, finches, larks, magpies, choughs, grouse, pheasants, and jays. Many of the birds which belong truly to this region migrate southward in winter. Snakes and lizards are comparatively scarce, but toads, frogs, and newts abound. The great similarity between the flora and fauna of Europe and North Africa indicates that land connections have recently existed across the Mediterranean from Africa to Spain and Italy.

The most common and widespread trees are the oak, fir, beech, birch, elm, pine, poplar, maple, and ash, while in the south the chestnut, plane, mulberry, olive, cork oak, lime, pomegranate, orange, laurel, myrtle, and fig abound. In north Africa, the date palm, doum palm, aloe, oleander, papyrus, and lotus are added. The tea plant and paper mulberry are natives of eastern Asia.

The North American Region consists of North America north of central Mexico. It possesses a great variety of climate and surface, but it is widest toward the north, and suddenly narrows in its warmest portion. A large extent of its interior is subject to great extremes of temperature,

and much of it is semi-arid or desert. It has recently been subjected to severe and widespread glaciation, which must have destroyed many of its inhabitants. It is not strange that its fauna is less rich and varied than that of the Eurasian region, which it most resembles.

Fig. 327. — North American animals.

Among its peculiar species are the star-nosed moles, weasels, and skunks, the prong-horned antelope, the bighorn or Rocky Mountain sheep, musk ox, muskrat, pouched rat, jumping mouse, vesper mouse, prairie dog, raccoon, tree porcupine, sewellel, opossum, salamander, rattlesnake, and horned toad. A large proportion of its birds are migratory. It is the birthplace of the horse and the camel, although both were extinct there at the time of settlement by Europeans. It possesses so many forms in common with Eurasia that

the two regions are sometimes united under the name of the *Holarctic Region*. The bison, reindeer, grizzly bear, moose, Arctic fox, lynx, wolf, marten, and beaver are characteristic and common to both, and point to a time when the two continents were broadly connected, probably in the region of Bering Strait.

The Fauna of Islands. — Continental islands generally possess a fauna similar to that of the neighboring continent, but much poorer in number and variety of forms. Oceanic islands are usually very poor in species of both plants and animals. Mammals are often entirely wanting. Birds and insects, having the power of flight, and reptiles, which in some unknown way are able to cross wide spaces of ocean, are more numerous. The conditions upon any small island or group of islands are so simple and uniform as to be unfavorable to the development of diversity among its inhabitants.

Summary. — All the evidence points to the conclusion that the land masses of the northern hemisphere are of great antiquity, and have been the birthplace of all the higher forms of life. In them are found the fossil remains of the ancestors of the animals still living there, and in older rocks the forerunners of those which now inhabit the southern hemisphere. As the southern lands were from time to time temporarily connected with the northern, successive waves of life flowed into them. There have been many minor movements back and forth, but in general the newer and higher forms have developed in the north and have forced the older and less competent to emigrate. Hence the faunas of the different regions become more and more unlike toward the southern extremities of the land, where primitive forms still survive. They are now most numerous in Australia, because there they have been longest cut off and protected from inva-

sion. The number and diversity of species and the density of animal population in each region are largely determined by the extent and variety of favorable conditions which prevail there. This law is modified by the growth or age of the region, by the efficiency of the barriers which surround it, and by the opportunities which have existed for foreign invasions. South America has been most fortunate in a combination of all these circumstances; hence the surpassing richness of its life. Africa and the Oriental Region are not far behind, while Australia is distinctly poor. At the extreme of poverty stand the small and isolated oceanic islands. Existing forms are not always found in regions best adapted to them, but in regions where their ancestors lived or to which they have been able to migrate from their ancestral home.

Life in the Sea. — No part of the ocean is devoid of life, and most of it is more densely populated than the land. The temperature of sea water varies as much between the surface and bottom as between the equator and the poles; consequently the distribution of life is in zones more strongly contrasted in a vertical than in a horizontal direction.

Shallow Waters. — The shallow waters, less than 600 feet in depth, are penetrated by the light and heat of the sun and are most populous. Their populousness is also due to the deposit of mud from the rivers, which furnishes suitable soil and food for plants and animals. This zone is quite definitely bounded by the "mud line" or outer limit of continental deposits. In this zone a luxuriant growth and variety of seaweeds afford food and protection for a still more numerous and varied animal life.

A sand bottom is inhabited by skates, soles, and flatfish, which are colored upon the upper side like the sand. A rock bottom supports fixed animals, such as barnacles, worms, polyps, sea anemones, sponges,

corals, and sea squirts, and affords suitable conditions for creeping or crawling animals like sea urchins, starfish, periwinkles, sea snails, lobsters, prawns, and crabs. The shallow equatorial waters in which the temperature never falls below 68° F. are the home of the coral polyp, where extensive reefs afford grazing ground for innumerable forms of life.

Fig. 328. – Marine mammals.

Surface Water. — The surface waters everywhere abound in free floating or swimming organisms. The largest seaweeds float freely without attachment to the soil and drift with the winds and currents. The surface waters teem with myriads of small animals which like the jellyfish rise at night and sink by day. The vast area, the abundance of *mineral food* in solution, the volume of sunlight, and the

uniformity of temperature are favorable to the growth of microscopic plants in such numbers as to furnish an inexhaustible supply of food for the animals of the sea.

Among large, free-swimming animals, fishes are the most abundant; but the great marine mammals, whales, porpoises, and dolphins, which can not breathe under water and resemble fish only in form, are included. Other mammals, like the seal, walrus, sea elephant, sea lion, sea bear, and manatee, resort to the land a part of the time for food, rest, protection, and breeding. Many fish, like the cod, herring, mackerel, and salmon, periodically visit shallow water or ascend rivers for the purpose of spawning.

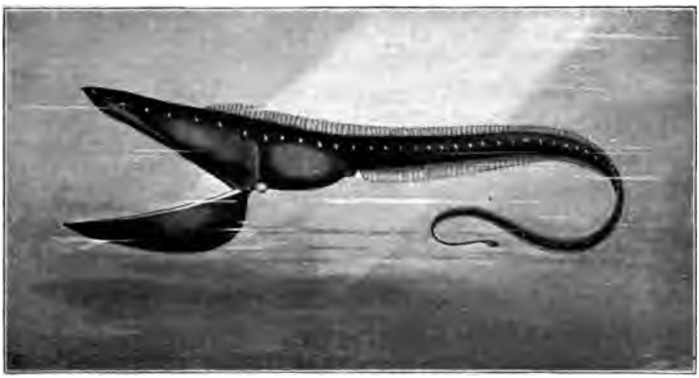


Fig. 329.—Deep-sea fish, with lanterns.

Deep Waters. — Fishes as well as invertebrates live near or upon the floor of the ocean at all depths. They prey upon one another or obtain food from the organic matter contained in the bottom mud or ooze, the supply of which is maintained by the sinking of plants and animals from the surface.

Some deep-sea animals are blind and some have large eyes. Many have limbs or antennæ of extraordinary length, which they use as feelers. Others are provided with organs which produce a phosphorescent light and serve as lanterns. Phosphorescence is also characteristic of the minute freely floating organisms which abound in the surface waters of

some parts of the ocean, and at night cause the water to glow with a soft radiance.

The warm tropical waters are characterized by animals which secrete lime shells, while in the cold polar waters lime-secreting organisms are few.

Temperature is the chief barrier to migration in the sea, but the polar waters of the two hemispheres are connected along the bottom by a continuous layer of water near the freezing point, and the marked similarity of the fauna of the Arctic and Antarctic oceans may be due to the free communication between them.

CHAPTER XXXII

THE GEOGRAPHY OF MAN

"And God said unto them, Be fruitful, and multiply, and replenish the earth, and subdue it." — GENESIS i. 28.

The Ascent of Man. — The evidence that man, like other animals, has descended from ancestors who were unlike himself is regarded by naturalists as conclusive. The difference in *mental* capacity between the most brutish man and the most manlike animal is so great that many people hesitate to believe that they are descended from a common ancestor. The *physical* differences between men and the higher animals do not seem so great. The most important are: (1) the ability to stand and to walk upright, and the adaptation of the feet and limbs for locomotion only; (2) the greater perfection of the arms and hands, which are left free for use solely as organs for grasping, holding, and performing delicate and complex movements; (3) the increased capacity of the skull and the greater size and complexity of the brain, which accompany and render possible the enormously greater development of the mental powers. The sutures of the brain case do not unite for twenty years or more, which enables the brain to continue to grow during that period. Thus the period of immaturity during which the child can be trained and educated is prolonged. The human animal only is highly educable and guided by intelligence and reason.

Stages of Culture and their Relation to Food Supply. — Men, like other animals, are dependent upon their environment for food, and the *stage of culture* or degree of ap-

proach toward civilization attained by any people depends largely upon the manner in which they provide for themselves the means of subsistence. The earliest men lived upon fruits, roots, seeds, and tubers found growing wild, and upon reptiles, insects, worms, and other vermin which they could capture. The history of the race has been one of slow progress from this lowest stage of savagery through barbarism to civilization. The discovery of the use of fire and the manufacture of axes, spearheads, knives, and other implements and weapons from stone enabled them to become hunters and fishermen, and added to their resources a relatively abundant supply of cooked meat. The invention of the bow and arrow was of prime importance, the power, range, and accuracy of this weapon giving its possessors a decided superiority in war and the chase. The invention of the art of making pottery from clay added to the conveniences of domestic life facilities for the storage of liquids and for cooking by boiling.

The Domestication of Animals. — As long as men depend for food supply upon native plants and the killing of wild animals, their means of subsistence is irregular and uncertain. A country can support only a sparse population, and these are necessarily scattered in small companies. Men can not rise out of savagery until they have placed their food supply upon an artificial basis. This was accomplished at a very early period in Eurasia, where men learned to keep cattle, horses, sheep, and goats under protection and control, and to obtain from them a constant supply of food in the form of milk and flesh. Animals capable of being thus domesticated were entirely absent from Australia, and nearly so from America; hence the aboriginal inhabitants of these continents, with few exceptions, did not rise above the savage state.

The Domestication of Plants. — The domestication of animals affords only a partial escape from savagery. Among a purely pastoral people the flocks and herds depend upon natural pasturage, found in semi-arid steppes or prairies, like those of western Asia, eastern Europe, and central North America, and must be led or driven about from place to place. Under such conditions men can not occupy fixed habitations, or gather in large numbers in one place. The domestication of plants is a more important step toward civilization than that of animals. The fruits most valuable for food supply are confined to the tropical regions. The fig, date palm, cocoa palm, breadfruit, banana, and plantain have formed the staple subsistence of millions of people. Of still greater value are roots and tubers like the potato, manioc, yam, and sweet potato. The most valuable of all are the cereal grains. In the Old World, wheat, barley, rye, rice, millet, durra, and other small grains have been raised from time immemorial. America was the home of maize, or Indian corn, in many respects the most valuable of all grains, especially for the use of primitive peoples. By its culture the people of Mexico and Peru had laid the foundation for the nearest approach to civilization ever attained on this continent before its discovery by Europeans.

The highest civilization is attainable only by a combination of agriculture and stock raising. When to these industries is added a knowledge of the art of smelting and refining iron ore, the physical basis of a high civilization is completed, and the *steel age*, in which all the leading peoples of the world are now living, is begun.

Varieties of the Human Species. — Of all species of animals, man is the most widely distributed. His intelligence enables him to live in all lands and all climates,

from Greenland to Tierra del Fuego, and from marshes and islands near sea level to the high Andes and Himalayas. From his cradle land, which was probably some part of Eurasia, he seems to have migrated in all directions, without definite purpose or destination, wherever the land connections of those remote times furnished a road. Led on by the pursuit of food, or driven from place to place by enemies, he penetrated every unoccupied land, and

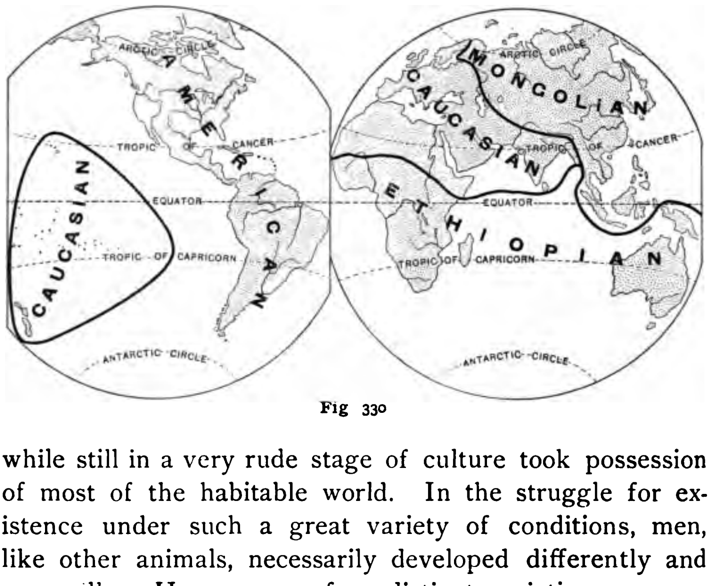


Fig 330

while still in a very rude stage of culture took possession of most of the habitable world. In the struggle for existence under such a great variety of conditions, men, like other animals, necessarily developed differently and unequally. Hence arose four distinct varieties or races, differing in physical and mental characteristics. The hot, moist, equatorial forests of central Africa produced a *black race* (Ethiopian), which spread over the whole of tropical Africa and the similar regions of the East Indies, which, together with Australia, formed a new center, where men of a somewhat different and lower type were devel-

oped. The high, arid plateaus of central Asia produced a *yellow race* (Mongolian), which spread over nearly the whole of Asia and the neighboring islands. The American continent produced a *red race* (American), which occupied its whole area for many centuries without interference from the rest of the world. North Africa and western Europe gave birth to a *white race* (Caucasian), which, in historic times, has spread thence over northern and southern Asia, America, south Africa, and Australia, dispossessing or gaining control of the aboriginal races. Figure 330 shows the distribution of the four races as it was previous to the modern migrations which began in the sixteenth century. The table on p. 389 shows their distinctive characteristics and present distribution.

Types of the Caucasian Race. — The peoples of each race, though alike in the characteristics mentioned on p. 389, differ in many minor details. Among the peoples of the Caucasian race there are three well-marked types.

(1) **North European or Teutonic.** — Blond or florid, with flaxen or reddish, glossy hair, blue eyes, long skull, and tall stature. Scandinavians, North Germans, Dutch, English, Scotch, Irish, and their descendants in America, Australia, and south Africa; West Persians, Afghans, many Hindus, and some other peoples of southwest Asia.

(2) **Alpine.** — Light brown or swarthy, with brown, wavy, dull hair, brown, gray, or black eyes, broad skull, and medium stature. Most French and Welsh, South Germans, Swiss, Russians, Poles, Bohemians, and other peoples of southeastern Europe; Armenians, East Persians, and the peoples of the eastern Pacific islands.

(3) **Mediterranean.** — Olive brown to almost black, with dark or black wiry hair, dark or black eyes, round skull, and small stature. Spanish and Portuguese and their descendants in America; some French, Welsh, and Irish; Italians and Greeks; Berbers, Egyptians, and other peoples of north Africa; Arabs, Syrians, and other peoples of southwest Asia; some Hindus.

The Population of the World according to races is estimated to be as follows: —

Fig. 331. – An Ethiopian.

Fig. 332. – A Mongolian.

Fig. 333. – An American.

Fig. 334. – A Caucasian.

Caucasians	770,000,000
Mongolians	540,000,000
Ethiopians	175,000,000
Americans	22,000,000
Total	1,507,000,000

	Ethiopian or Black Race (Fig. 331)	Mongolian or Yellow Race (Fig. 332)	American or Red Race (Fig. 333)	Caucasian or White Race (Fig. 334)
Home	Central Africa.	Central Asia.	America.	Europe, north Africa.
Color	Chocolate to black.	Yellowish to brown.	Coppery red.	Pale white to nearly black.
Hair	Black, frizzly, woolly, or shaggy.	Black, long, straight, coarse; beard scanty.	Black, long, straight, coarse; beard scanty.	Flaxen, red, brown, and black, straight, wavy, or curly; beard heavy.
Skull	Long and narrow.	Broad and round.	Variable.	Variable.
Jaws	Projecting.	Slightly projecting.	Massive.	Not projecting, small.
Lips	Thick and rolling.	Rather thin.	Medium.	Thin, or rather full.
Nose	Broad and flat.	Small and concave.	Large, straight or aquiline.	Straight and narrow, with high bridge.
Eyes	Large, round, black; yellowish cornea.	Small, black, and oblique.	Small, black, and deep-set.	Blue, gray, brown, or black.
Culture	Very low; no science or letters; arts confined to agriculture, weaving, pottery, woodwork, and the use of simple implements of iron.	Ranges from savagery to civilization; agriculture and some arts well developed; letters common, but science and literature stagnant.	Ranges from the lowest savagery to low civilization; agriculture and the arts moderately developed in the highest; letters and science rudimentary.	Civilized, or enlightened; arts, industries, science, literature, and social institutions highly developed.
Present range	Africa, United States, West Indies, Brazil, Peru, Guiana, Australia, New Guinea, and neighboring islands.	All Asia, except India, Persia, Arabia, and Afghanistan; East Indies and Asiatic islands; northeastern Europe, Turkey.	Most of South and Central America, Mexico, Alaska, and Canada. and some small areas of the United States.	Europe, north and south Africa, northern and southern Asia, India, America, Australia, New Zealand, and many other islands.

Civilized Men. — No people of Ethiopian race has ever risen, without help from some other race, above a condition of barbarism. The same is true of the American race with the exception of the Aztecs of Mexico and the Incas of Peru. Native civilization belongs chiefly to the Caucasian race, and in a lesser degree to the Mongolian. As in the case of other animals, man has attained his highest development in the north temperate zone, within which all the great civilizations of ancient and modern times have sprung up. The great centers of civilization have been located upon lowlands which either were traversed by large rivers, or were easily accessible from the sea, or both. This is true of China, India, Babylonia, Egypt, Greece, Italy, Great Britain, and the countries of western Europe.

Man can live in the north frigid zone, but it furnishes only the bare necessities of life, and the whole of human energy must be expended in obtaining them. In the torrid zone the climate is oppressive and hardly permits prolonged exertion. Clothing and shelter are scarcely needed, and food can be procured without much effort or forethought. The luxuriance of plant and animal life is so great that man is overwhelmed by it and remains insignificant. In temperate climates food and clothing may be obtained in abundance, but only by the exercise of industry and invention. The inclement and unproductive winter makes it necessary to provide beforehand substantial shelter and a supply of food. These conditions stimulate men to exert their physical and mental powers, and their efforts are rewarded with comforts and luxuries. Well-watered lowlands are very productive, especially of the cereal grains. The presence of navigable rivers or the sea renders travel and transportation easy, leading to commerce and that interchange of ideas characteristic of enlightened peoples.

Influence of Physical Features. — The degree of civilization, power, and influence attained by a state or people depends upon numerous physical factors belonging to the territory which it occupies. The *latitude*, *distance from the sea*, and *relief* of a country largely determine its

temperature, rainfall, and soil, consequently its products and the occupations of its people. Switzerland, the Scotch highlands, and Norway produce a different type of people from those which inhabit the low plains to the south of them. A long and irregular *coast line*, with arms of the sea extending far into the land, constitutes one of the most favorable conditions for human occupation. The contrast between Europe and Africa, and between Great Britain and Australia, is in this respect very great. *Mountain ranges* act as barriers to rainfall, making it unequal upon opposite slopes, form the natural boundaries of states, and in their disturbed and dislocated structure expose veins of coal, iron, and other minerals. A network of *rivers and lakes* affords opportunities for internal commerce and furnishes water power for manufactures. The *size* or area of a country exerts no small influence upon the condition of its people. The area of the United States is so large that it includes all temperatures from sub-tropical to frigid, all rain belts from the heavy rainfall of the Pacific and Gulf coasts to the almost rainless deserts of the Great Basin, all relief forms from the low plains of the Atlantic coast and Mississippi basin to the high plateaus and mountains of the western half. Hence its agricultural and mineral products are so varied and abundant as to render it largely independent of the rest of the world, and to constitute the largest resources of natural wealth belonging to any one people in the world.

Natural Resources. — Civilized men are learning more and more how to modify the conditions of their environment and to turn them to their own advantage. They are everywhere engaged in developing the natural resources of their country. These consist of three classes: (1) *agricultural products*, both vegetable and animal, which depend

upon the soil, but also upon the energy supplied by the sun in the form of heat and light, and upon water vapor in the air; (2) *mineral products*, such as coal, iron, copper, lead, tin, zinc, gold, silver, salt, and building stones, which are contained in the crust of the earth, and the quantity of which can not be increased; (3) *resources which furnish power*, such as coal, petroleum, natural gas, water power, and wind power, used to run machinery. Of all these, agricultural resources furnish the foundation of the state. While the quantity is not unlimited, it can be increased by skillful management so as to support a population more dense than now exists anywhere in the world except in China and India. Of mineral resources, coal and iron ore — the indispensable materials of modern civilization — are by far the most important. These are not now being formed, and the exhaustion of the supply seems to be a certainty of the remote future. The more extensive use of water power, as at Niagara Falls, will make the consumption of coal less rapid. The increasing use of machinery involves the use of greater quantities of iron and other metals and of fuel, the growth of manufacture, and the extension of commerce. The building of railways has rendered most other means of land transportation useless or of less importance. The use of large and swift steamships has changed the sea from an impassable barrier to a means of easy communication between peoples. Within a century the world has shrunk for purposes of human intercourse to practically one tenth its former size. The most enterprising nations are extending their lines of commerce and influence in every direction, and the more prolific peoples, like the British, Germans, Russians, and the people of the United States, are expanding by annexation and colonization to occupy, control, and develop *nearly every* portion of the habitable globe.

APPENDIX I

THE EQUIPMENT OF A GEOGRAPHICAL LABORATORY[1]

Geography can not be learned without suitable material and appliances any more profitably than physics or chemistry. The apparatus required consists of models, maps, pictures, specimens, and instruments for work in meteorology.

Models. — Many models of especially instructive regions which have been adequately surveyed, are now available, but really good models are necessarily rather expensive. Those of crude and inaccurate construction, and with vertical heights greatly exaggerated, are liable to teach more error than truth, and are worse than useless. The following models (sometimes called relief-maps) are among the best and most useful.

Fig. 335. — Howell's model of the United States.

The United States, Gulf of Mexico, and portions of the Atlantic and Pacific oceans, constructed as a section of a sphere 16 feet in diameter. Horizontal scale, 40 miles to 1 inch: vertical scale, 8 miles to 1 inch. Size 4 ft. 2 in. × 8 ft. $125.00.

[1] See Journal of School Geography, **2**, 170.

A copy of the above on a scale of 120 miles to 1 inch. Size 1 ft. 6 in. × 2 ft. 10 in. Easily portable. $25.00.

The Uinta and Wasatch mountains, showing folded and faulted mountains, canyons of Green River, escarpments, and dip slopes. Scale 4 miles to 1 inch. Vertical heights exaggerated 2 to 1. Size 4 ft. × 4 ft. 2 in. $125.00.

The Grand Canyon of the Colorado and the plateaus of southern Utah. Horizontal and vertical scales 2 miles to 1 inch. Size 6 ft. × 6 ft. $125.00.

The Henry Mountains and vicinity. Scale 2 miles to 1 inch. Size 3 ft. × 3 ft. 6 in. $30.00.

Stereogram of the Henry Mountains showing the same region as the preceding as it would be if the eroded material were restored. $12.00.

Southern New England. Scale 2 miles to 1 inch. Size 5 ft. 7 in. × 8 ft. 4 in. $135.00.

The Chattanooga district. Scale 1 mile to 1 inch. Size 3 ft. 4 in. × 3 ft. 10 in. $50.00.

New York. Horizontal scale 12 miles to 1 inch; vertical heights exaggerated 5 to 1. Size 2 ft. 1 in. × 2 ft. 10 in. $25.00.

Mt. Shasta. Size 3 ft. 3 in. × 3 ft. 4 in. $40.00.

Mt. Vesuvius. Size 2 ft. × 2 ft. 6 in. $10.00.

These models are made and sold by Edwin E. Howell, 612, 17th St. N.W., Washington, D.C.

Mr. Howell also furnishes a set of five models of the continents at $150.00.

Professor John F. Newsom, Leland Stanford Junior University, California, furnishes the following six models:

Morrisons Cove. Penn., showing anticlinal and synclinal folds. Size 1.9 ft. × 2.3 ft. $35.00.

Allamakee County, Iowa, showing topographic forms in a region of horizontal strata. Size 2.3 ft. × 2.5 ft. $20.00.

Marysville Buttes, Cal., showing volcanic cone surrounded by sedimentary strata. Size 1.8 ft. × 1.8 ft. $12.00.

Ideal Restoration of Marysville Buttes, showing maximum development of a volcano. $5.00.

Crater Lake, Oregon. Size 1.1 ft. × 1.4 ft. $7.00.

Sectioned model of the Leadville region, Col., showing intense folding, faulting, and igneous intrusions. Size 2.6 ft. × 3.2 ft. $85.00.

Harvard Geographical Models, a set of three, each 25 × 19 inches, showing (1) Mountains Bordering the Sea, (2) Coastal Plain and Mountains, (3) Embayed Mountains. Ginn & Co., Boston. Per set, $20.00.

Jones's New Model of the Earth, mounted as a globe, 20 inches in diameter. Vertical scale exaggerated 20 times. A. H. Andrews & Co., Chicago. $50.00.

Maps. — Large-scale maps for the wall or table are indispensable for the class room, and can now be obtained at small expense.[1]

Map of the Alluvial Valley of the Mississippi River. Scale 5 miles to 1 inch. 8 sheets. Per set, $1.00. Map of the Alluvial Valley of the Upper Mississippi River. 4 sheets. Per set, 70 cents. Map of the Lower Mississippi River in 32 sheets. Scale 1 mile to 1 inch. Per set, $1.60. Map of the Upper Mississippi River in 30 sheets. Per set, $1.50. Address Secretary Mississippi River Commission, St. Louis, Mo.

Map of the Missouri River from its mouth to Three Forks, Mont. Scale 1 mile to 1 inch. 96 sheets, 5 cents per sheet. Address Secretary Missouri River Commission, St. Louis, Mo.

Survey of the Northern and Northwestern Lakes. Price list may be obtained from United States Engineer's Office, Detroit, Mich. The Niagara Falls and Lake St. Clair charts are of especial value.

United States Coast and Geodetic Survey Charts. An illustrated catalogue of charts may be obtained on request from the Superintendent, Washington, D.C. Old charts which have been superseded, but are not less valuable for teaching purposes, may often be obtained free.

Topographical Atlas of New Jersey; 20 sheets at 25 cents each, or the set, $5.00. Geological Survey of New Jersey, Trenton.

Topographical Atlas of Massachusetts; 54 sheets at 5 cents each, or the set $4.25. Topographical Survey of Massachusetts, Boston.

Topographical Map of Rhode Island, $2.00. Topographical Survey of Rhode Island, Providence.

Topographic Atlas of the United States. Published in sheets, many of which are accompanied by geological maps, pictures, and descriptive text, the collection being called a Folio (in the following pages folios are marked thus: *). Relief shown by contour lines. Single sheets

[1] Consult Governmental Maps for Use in Schools, Henry Holt & Co., N.Y. 30 cents. Also Journal of School Geography, **1**, 200.

5 cents, or $2.00 per 100. Folios, 25 cents each. Price list sent on application to the Director, U. S. G. S., Washington, D.C. Out of several thousand the following are especially useful: —

Physiographic Types, Folio 1: Ten maps with descriptive text: A Region in Youth, A Region in Maturity, A Region in Old Age, A Rejuvenated Region, A Young Volcanic Mountain, Moraines, Drumlins, River Flood Plains, A Fiord Coast, A Barrier Beach Coast.

Folio 2: A Coast Swamp, A Graded River, An Overloaded Stream, Appalachian Ridges, Ozark Ridges, Ozark Plateau, Hogbacks, Volcanic Peaks, Plateaus and Necks, Alluvial Cones, A Crater.

A single sheet map of the United States. Relief shown by nine shades of brown color; also with relief shown by contours.

Marine Plains: Glassboro, N.J.

Fluviatile Plains: Marysville,* Cal.

Lacustrine Plains: Sierraville, Lassen Peak,* Cal.; Tooele Valley, Utah; Disaster, Paradise, Nev.

Glacial Plains: Marion, Ia.

Dissected Plains: Spottsylvania, Farmville, Palmyra, Va.; McCormick, Ga.; Clanton, Ala.

Upland Plains: Springfield, Bolivar, Tuscumbia, Fulton, Mo.; Iola, Kan.

Plateaus: Fort Defiance, Ariz.; Las Animas, Kit Carson, Lamar, Granada, Col.

Dissected Plateaus: Mesa de Maya, Col.; Marsh Pass, Ariz.; Coldwater, Meade, Kan.; Hazard, Salyersville, Warfield, Ky.; Kanawha Falls, Nicholas, Huntersville, Hinton, W. Va.; Scottsboro, Ala.; Sewanee, Tenn.; Marshall, Ark.; Gaines, Pa.

Trenched Plateaus, Cliffs, Buttes, Canyons: Kaibab, Echo Cliffs, Ariz.; Escalante, Price River, Kanab, Utah.

Denuded Plateaus, Escarpments, Outliers, Mesas: Watrous, Corazon, N. Mex.; Sewanee,* Tenn.; Kaaterskill, N.Y.; East Tavaputs, Utah; Tusayan, Ft. Defiance, Ariz.; Abilene, Brownwood, Tex.

Basin Ranges: Tooele Valley, Utah; Disaster, Nev.; Alturas, Cal.

Rocky Mountains: Canyon City, Huerfano Park, Pikes Peak,* Platte Canyon, Telluride,* Col.; Livingston,* Mont.; Yellowstone National Park,* Wyo.

Wasatch and Uinta Mountains: Salt Lake, Uinta, Utah.

Black Hills: Rapid, S.D.

* A folio (see p. 395).

Appalachian Mountains: Lykens, Pottsville, Harrisburg, Hummelstown, Pa.; Monterey,* Franklin,* Estillville,* Va.; Piedmont,* W.Va.; Mt. Mitchell, Asheville, Pisgah, N.C.; Briceville,* Cleveland,* Loudon,* Pikeville,* Kingston,* Chattanooga,* Tenn.; Ringgold,* Atlanta, Ga.; Gadsden,* Stevenson,* Ala.

Mountain Highlands: Hawley, Chesterfield, Granville, Becket, Mass.; Winsted, Bridgeport, Cornwall, Derby, Conn.; Hackettstown, N.J.

Volcanoes: Shasta, Marysville,* Cal.; San Francisco Mt., Ariz.; Mt. Taylor, N. Mex.

Lava Plains: Modoc Lava Bed, Cal.; Bisuka, Boise, Silver City, Nampa, Ida.

Laccolites: San Rafael, Henry Mountains, Utah.

Volcanic Dikes, Mesas, and Plugs: Absaroka,* Wyo.; Elmoro,* Col.; Greenfield, Holyoke,* Mass.

Flood Plains: Donaldsonville, Mt. Airy, Pointe a la Hache, Gibson, Houma, La.; Fort Payne, Ala.; St. Louis (east sheet), Independence, Marshall, Mo.; Junction City, Kan.; Minden, Neb.

Meandering Valleys: Versailles, Tuscumbia, Mo.; Palo Pinto, Granbury, Tex.

Transverse Valleys and Water Gaps: West Point, Tarrytown, Harlem, N.Y.; Harpers Ferry,* Va.; Harrisburg, Delaware Water Gap, Pa.

Filled Valleys: Lake, Wyo.; Independence, Marshall, Mo.; Disaster, Granite Ridge, Long Valley, Nev.

Migrating Divides and Trellised Drainage: Doylestown, Pa.; Dahlonega, Gainesville, Walhalla, Ga.; Franklin, Pocahontas, Va.

Hudson River: Hoosick, Troy, Albany, Coxsackie, Catskill, Poughkeepsie, N.Y.

Cataracts and Gorges: Rochester (special), Niagara Falls (special), N.Y.; Minneapolis, Minn.; Great Falls, Mont.; Yellowstone National Park,* Wyo.

Moraines, Drumlins: Madison, Sun Prairie, Waterloo, Watertown, Oconomowoc, Wis.; Charlestown, R.I.; Stonington, Conn.

Cirques: Anthracite and Crested Butte,* Col.

Glacial Lakes: Webster, Mass.; Madison, Geneva, Wis.

Finger Lakes: Ithaca, Elmira, N.Y.

Volcanic Lakes: Ashland, Crater Lake (special), Ore.

Old Lake Outlets: Ottawa, Marseilles, Lasalle, Calumet, Des Plaines, Ill.; Oneida, Oriskany, Schenectady, Cohoes, N.Y.

* A folio (see p. 395).

River Terraces: Springfield, Mass.; Hartford, Conn.

Drowned Valleys and Fiords: Wicomico, Md.; Fredericksburg,* Nomini,* Mt. Vernon, Va.; Norwich, New London, Conn.; Portland, Casco Bay, Boothbay, Me.

Bays and Bars: Duxbury, Nahant, Boston, Mass.; Ontario Beach, N.Y.; Duluth, Minn.; San Francisco, Cal.; Seattle,* Tacoma,* Wash.

Barrier Beaches and Spits: Sandy Hook, Asbury Park, Barnegat, Long Beach, N.J.; Marthas Vineyard, Gay Head, Provincetown, Mass.

Foreign Maps. — Most of the European countries have published governmental maps on a large scale, many of which are models of the cartographic art. Consult "Large-Scale Maps as Geographical Illustrations," by Davis, Journal of Geology, **4**, 484.

Pictures and Lantern Slides. — Pictures are now so common and cheap that a very good collection can be made from magazines, railroad advertisements, and newspapers. A few collections of large photographic or autotype pictures containing many illustrations of geographical features have been made. Scenes from Every Land, 500 photographs, J. W. Jones, Springfield, Ohio, $5.00; America Photographed, 210 views, Donahue & Hennebery, Chicago, $1.00; and Our Own Country, 500 pictures with descriptive text, The National Co., St. Louis, Mo., $3.50, may be recommended.

The lantern for projection has become the common adjunct of school instruction. It is now supplied by all dealers in scientific instruments. E. E. Howell, Washington, D.C., supplies a list of slides selected by Professor Davis. The American Bureau of Geography, Winona, Minn., has undertaken to supply good photographs and slides. Announcements are made in its Bulletin, quarterly, $1.00 per year.

Suggestive exercises in laboratory work in geography will be found in Journal of School Geography, **1**, 172, 204; **3**, 368.

APPENDIX II

METEOROLOGICAL INSTRUMENTS[1]

The Measurement of Temperature. — *Standard Thermometer* ($2.75). Temperature is measured by a thermometer. This instrument consists of a small glass tube with a bulb at one end. The bulb and part of the

* *A Folio* (see p. 395).

[1] See Journal of School Geography, **3**, 241.

tube are filled with mercury or alcohol, the air is removed and the tube closed. The bulb is then placed in melting ice and the point at which the top of the column stands is marked 32° and called the freezing point. The bulb is then placed in the steam above boiling water, and the point at which the top of the column stands is marked 212° and called the boiling point. The space between is divided into 180 equal degrees and the graduation is extended below 32° on the same scale. This is called the Fahrenheit scale. The Centigrade scale, which marks the freezing point 0° and the boiling point 100°, is also much used. In determining the error of a common thermometer by comparison with a standard, the comparison should be made at as many different points in the scale as possible.

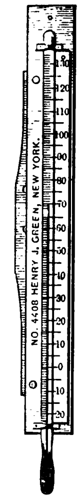


Fig. 336. Standard thermometer.

Maximum and Minimum Thermometers ($8.25). These instruments should be mounted together upon a board as shown in Fig. 337. The tube of the maximum is bent and constricted just above the bulb. As the temperature rises, the mercury passes up the tube. When the temperature falls, the column breaks at the constriction and remains at the highest point reached. After reading, the instrument should be set by rotating it rapidly around the pin at its upper end.

The minimum is filled with alcohol and contains a steel index. When the temperature falls, the index is dragged downward by the surface tension of the alcohol. When the temperature rises, the index

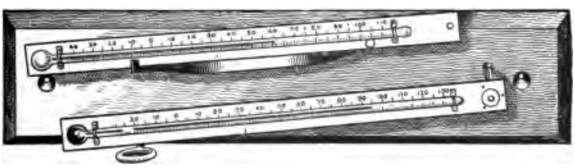


Fig. 337.

is left behind at the lowest point reached. The instrument is set by raising the bulb until the index slides down to the surface of the alcohol.

Shelter. Thermometers should be exposed in a latticed shelter in an open space away from buildings and four to ten feet above the ground.

If a shelter is not available, they may be placed outside a north window in such a position that they may be read without opening the window.

Fig. 338. — A latticed shelter.

The Measurement of Pressure. — *The Mercurial Barometer* ($5.75 to $30.00) consists of a glass tube and cup containing mercury, inclosed in a metal tube for protection and provided with devices for convenient and accurate reading. The distance to be measured is the difference between the level of the mercury in the tube and its level in the cup. As the mercury falls in the tube it rises in the cup, and *vice versa:* therefore it is necessary to bring the mercury in the cup to a certain fixed level before reading. The cup has a leather bottom which is pressed by the screw *C*, Fig. 339. By turning this screw, the level of the mercury is adjusted so that its surface just touches the point of an ivory pin at *B*. This is the zero point of the scale. The zero is sometimes marked by a black line on the outside of the cup. In the upper part of the metal tube two slots are cut so that the mercury column can be seen. Two metal pieces slide in the slots and are moved by the screw *E*. Placing the eye in a position where the lower edge of the front piece just hides the lower edge of the back piece, move both pieces until their lower edges just cut off the light between themselves and the surface of the mercury at the center of the tube. To the metal tube is fastened a scale graduated into inches and *tenths.* The hundredths are read from the *vernier*, or

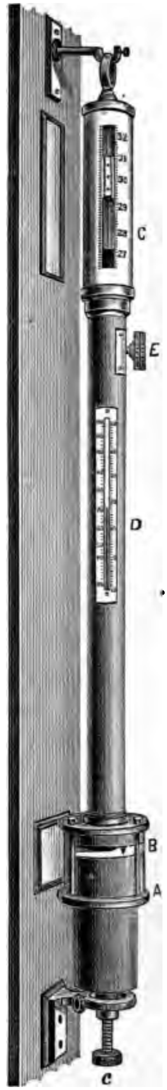


Fig. 339. — Mercurial barometer.

sliding piece, being indicated by the line on the vernier which coincides with a line on the fixed scale. The reading in Fig. 340 is 29.25 inches. Some barometers are read without a vernier.

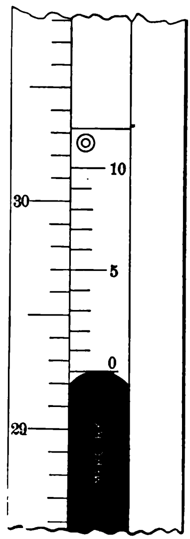


Fig. 340.

The mercury of the barometer is expanded by heat, and when the temperature is high it requires a longer column to balance the air pressure than when the temperature is low. It is therefore necessary to read the attached thermometer at *D*, and to correct the barometer reading for temperature.

In drawing isobaric maps the observed pressures are generally reduced to what they would be if the observing station were at sea level. This is done by adding the length of a column of mercury which would balance a column of air extending from sea level up to the station. Tables for the reduction of the barometer reading to 32° F. and to sea level are given on pp. 406, 407, and in Ward's Practical Exercises in Elementary Meteorology.

The Aneroid Barometer ($6.00 to $15.00) indicates pressure by the expansion and contraction of a vacuous metal box, the movement of which is communicated to a pointer like a clock hand, which revolves over a circular scale. If compensated for temperature, this instrument is accurate and convenient.

Fig. 341.—Aneroid barometer.

The Measurement of Humidity.—*The Hygrometer* ($6.50) consists of two similar thermometers mounted upon a board. The bulb of one is kept wet by being covered with a lamp wick which dips into a cup of pure water. The evaporation of the water cools the mercury and makes it stand lower than in the dry thermometer. If the air is dry, evaporation is rapid, and the difference between the two thermometers may be 15° or 20°. If the air is damp, evaporation is slow and the difference is small. The indications of the hygrometer are made definite by reference to tables. See pp. 408, 409; or Psychrometric Tables, published

by the U.S. Weather Bureau (price 10 cents); or Ward's Practical Exercises in Meteorology. The wet bulb should be fanned before reading, to prevent the accumulation of vapor near the instrument.

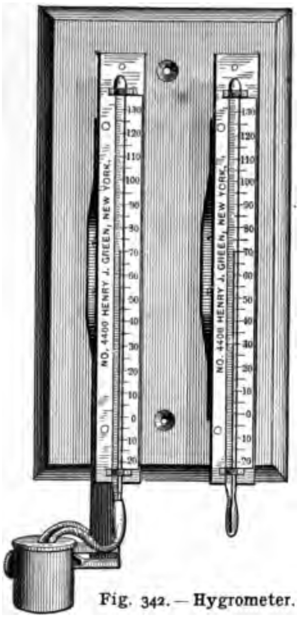


Fig. 342. — Hygrometer.

Any thermometer may be made to serve as a hygrometer by covering its bulb with wet muslin and swinging it around in the air by an attached cord until the mercury ceases to fall. Its reading should be compared with that of a similar dry thermometer. This instrument is called the *sling psychrometer*.

The Measurement of Precipitation. — *The Rain Gauge* ($1.25 to $5.25) is a metal cylinder having an inside diameter of 8 inches. The receiver is funnel-shaped and carries the water into a measuring tube whose area of cross section is one tenth that of the receiver. Thus one tenth of an inch of rainfall gives a depth of 1 inch of water in the tube. The depth is measured by a stick graduated in inches and tenths. The gauge should be mounted in a vertical position several feet above the ground in an open space at a distance from buildings and trees, and read and emptied every morning. Snow is estimated as water after melting.

The Thermograph and Barograph ($30.00 each) are instruments which make continuous records of temperature and pressure upon a strip of paper. They are indispensable for a thorough and comprehensive study of the weather. Instructions for their use are furnished by the dealers.

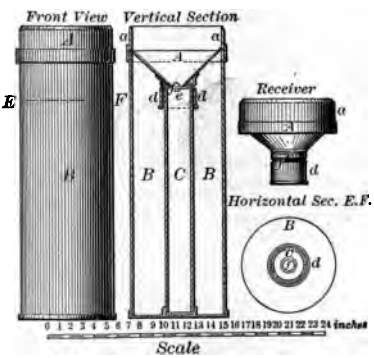


Fig. 343. — Rain gauge.

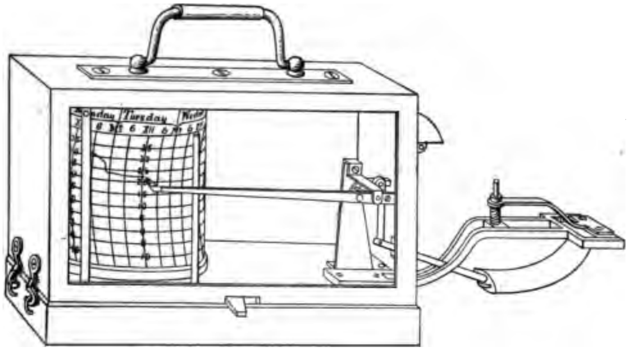


Fig. 344. — Thermograph.

Measurement of the Wind. — The direction of the wind can not be determined with accuracy without the use of a vane. The best vane is

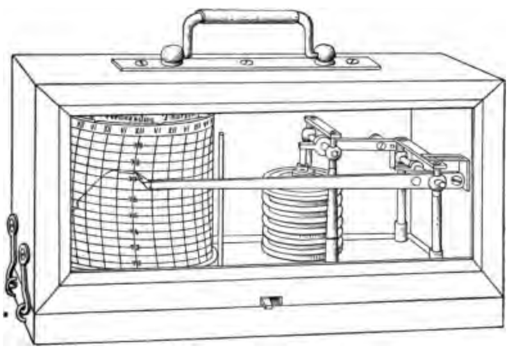


Fig. 345. — Barograph.

made of wood 6 feet long, and has a divided tail, the two parts making an angle of 22½°. It should be placed in a position above all trees and buildings.

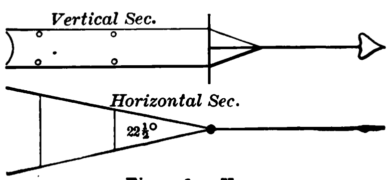


Fig. 346. Vane.

The Anemometer is a windmill with cup-shaped arms which records by the number of its revolutions the wind velocity. For purposes of elementary study it is sufficient to estimate the wind velocity according to the following scale.

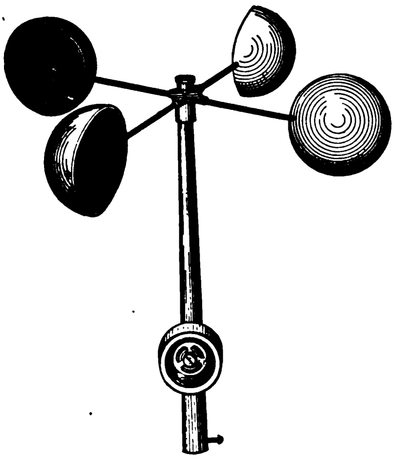


Fig. 347. — Anemometer.

0. Calm.
1. Light, 2–5 miles per hour, moving leaves.
2. Moderate, 7–10 miles, moving branches.
3. Brisk, 18–20 miles, swaying branches, blowing up dust.
4. High, 27–30 miles, swaying trees, blowing up twigs.
5. Gale, 45–50 miles, breaking branches, loosening bricks, signs, etc.
6. Hurricane, 75 miles, destroying everything.

Meteorological instruments are furnished by many firms: Queen & Co., Philadelphia, Pa.; H. J. Green, 1191 Bedford Ave., Brooklyn, N.Y.; L. E. Knott Apparatus Co., Boston, Mass.; Julien P. Friez, Baltimore, Md.

Form for Meteorological Record

Date.	Hour.	Pressure.	Temperature.				Rel. Hum.	Wind.		Cloud.		Precipit.	
			Dry.	Wet.	Max.	Min.		Direction.	Velocity.	Kind.	Amount.	Kind.	Amount.

The signs used on the U. S. Weather Maps may be used for wind direction, amount of cloud, and kind of precipitation.

A laboratory course in elementary meteorology is outlined in the *Journal of School Geography*, 1, 41; 2, 2, 56, 96, 104, 139.

Use of the Tables. — The tables on pp. 406–409 are almost self-explanatory; but students not accustomed to the use of such tables should study the following explanations of their use.

(1) *Temperature corrections for barometer readings* (p. 406), sometimes called "tables for reducing barometer readings to 32°." In the first column, in heavy-faced type, are temperatures from 0° to 100°, and on the same line with each temperature are printed, in ordinary light-faced type, eight different numbers in as many columns. The correction to be applied is the number in the column with the heading (in heavy-faced type) which is nearest the barometer reading. For instance, if a barometer reads 28.21, and the attached thermometer 70°, the temperature correction is found in the column headed 28, and on the line with 70°. Applying the correction, .11, we have 28.10 as the corrected reading. *For temperatures below 28° the correction is to be added, but for temperatures above 28° the correction is to be subtracted.*

(2) *Table for reducing barometer readings to sea level* (p. 407). As in the other tables, the known data are printed in heavy-faced type, and the quantities given by the table in light-faced type. For any particular elevation, the amount to be added varies with the temperature. For instance, if the elevation is 1200 feet, the amount is 1.43 at 0° temperature, 1.40 at 10°, and so on. If the barometer reading at elevation 1200 feet, corrected for temperature, is 28.10, and the air temperature is 70°, the amount to be added is found from the table to be 1.24. The reading as reduced to sea level is therefore 29.34.

(3) *Table for finding relative humidity* (pp. 408, 409). The various columns in the three parts of this table are headed by numbers in heavy-faced type from 1 to 42, each representing a possible difference between the reading of the dry thermometer and that of the wet-bulb thermometer at the same time, *the reading of the wet-bulb thermometer being always the lower.* On each line of the table are printed, in light-faced type, the various percentages of relative humidity for a certain temperature (printed in heavy-faced type at the left of the table) as given by the dry thermometer. For instance, if the temperature (dry thermometer) is 70°, a difference of 1° in the readings of the dry and wet-bulb thermometers indicates a relative humidity of 95 per cent (p. 408); a difference of 2°, a relative humidity of 90 per cent; a difference of 15°, a relative humidity of 37 per cent (p. 409); and so on.

The table on pp. 408, 409, is correct for a barometrical pressure of 29 inches, and approximately correct for all other ordinary pressures.

TEMPERATURE CORRECTIONS FOR BAROMETER READINGS: AMOUNTS TO BE *Added*

Temperature	Barometer reading, inches							
	24	25	26	27	28	29	30	31
0°	.06	.07	.07	.07	.07	.08	.08	.08
2°	.06	.06	.06	.07	.07	.07	.07	.08
4°	.05	.06	.06	.06	.06	.07	.07	.07
6°	.05	.05	.05	.06	.06	.06	.06	.06
8°	.05	.05	.05	.05	.05	.05	.06	.06
10°	.04	.04	.04	.05	.05	.05	.05	.05
12°	.04	.04	.04	.04	.04	.04	.05	.05
14°	.03	.03	.04	.04	.04	.04	.04	.04
16°	.03	.03	.03	.03	.03	.03	.03	.04
18°	.02	.02	.03	.03	.03	.03	.03	.03
20°	.02	02	.02	.02	.02	.02	.02	.02
22°	.01	.02	.02	.02	.02	.02	.02	.02
24°	.01	.01	.01	.01	.01	.01	.01	.01
26°	.01	.01	.01	.01	.01	.01	.01	.01
28°	.00	.00	.00	.00	.00	.00	.00	.00

TEMPERATURE CORRECTIONS FOR BAROMETER READINGS: AMOUNTS TO BE *Subtracted*

Temperature	Barometer reading, inches							
	24	25	26	27	28	29	30	31
29°	.00	.00	.00	.00	.00	.00	.00	.00
30°	.00	.00	.00	.00	.00	.00	.00	.00
31°	.01	.01	.01	.01	.01	.01	.01	.01
32°	.01	.01	.01	.01	.01	.01	.01	.01
33°	.01	.01	.01	.01	.01	.01	.01	.01
34°	.01	.01	.01	.01	.01	.01	.02	.02
35°	.01	.01	.02	.02	.02	.02	.02	.02
36°	.02	.02	.02	.02	.02	.02	.02	.02
37°	.02	.02	.02	.02	.02	.02	.02	.02
38°	.02	.02	.02	.02	.02	.03	.03	.03
39°	.02	.02	.02	.03	.03	.03	.03	.03
40°	.03	.03	.03	.03	.03	.03	.03	.03
41°	.03	.03	.03	.03	.03	.03	.03	.04
42°	.03	.03	.03	.03	.03	.04	.04	.04
43°	.03	.03	.03	.04	.04	.04	.04	.04
44°	.03	.04	.04	.04	.04	.04	.04	.04
45°	.04	.04	.04	.04	.04	.04	.05	.05
46°	.04	.04	.04	.04	.04	.05	.05	.05
47°	.04	.04	.04	.05	.05	.05	.05	.05
48°	.04	.04	.05	.05	.05	.05	.05	.05
49°	.04	.05	.05	.05	.05	.05	.06	.06
50°	.05	.05	.05	.05	.05	.06	.06	.06
51°	.05	.05	.05	.06	.06	.06	.06	.06
52°	.05	.05	.06	.06	.06	.06	.06	.07
53°	.05	.06	.06	.06	.06	.06	.07	.07

TEMPERATURE CORRECTIONS FOR BAROMETER READINGS: AMOUNTS TO BE *Subtracted*

Temperature	Barometer reading, inches							
	24	25	26	27	28	29	30	31
54°	.06	.06	.06	.06	.06	.07	.07	.07
55°	.06	.06	.06	.06	.07	.07	.07	.07
56°	.06	.06	.06	.07	.07	.07	.07	.08
57°	.06	.06	.07	.07	.07	.08	.08	.08
58°	.06	.07	.07	.07	.07	.08	.08	.08
59°	.07	.07	.07	.07	.08	.08	.08	.09
60°	.07	.07	.07	.08	.08	.08	.09	.09
61°	.07	.07	.08	.08	.08	.09	.09	.09
62°	.07	.08	.08	.08	.09	.09	.09	.09
63°	.08	.08	.08	.08	.09	.09	.09	.10
64°	.08	.08	.08	.09	.09	.09	.10	.10
65°	.08	.08	.09	.09	.09	.10	.10	.10
66°	.08	.09	.09	.09	.10	.10	.10	.11
67°	.08	.09	.09	.09	.10	.10	.10	.11
68°	.09	.09	.09	.10	.10	.10	.11	.11
69°	.09	.09	.10	.10	.10	.11	.11	.11
70°	.09	.09	.10	.10	.11	.11	.11	.12
71°	.09	.10	.10	.10	.11	.11	.12	.12
72°	.09	.10	.10	.11	.11	.11	.12	.12
73°	.10	.10	.10	.11	.11	.12	.12	.12
74°	.10	.10	.11	.11	.12	.12	.12	.13
75°	.10	.11	.11	.11	.12	.12	.13	.13
76°	.10	.11	.11	.12	.12	.12	.13	.13
77°	.11	.11	.11	.12	.12	.13	.13	.14
78°	.11	.11	.12	.12	.13	.13	.13	.14
79°	.11	.11	.12	.12	.13	.13	.14	.14
80°	.11	.12	.12	.13	.13	.14	.14	.14
81°	.11	.12	.12	.13	.13	.14	.14	.15
82°	.12	.12	.13	.13	.14	.14	.15	.15
83°	.12	.12	.13	.13	.14	.14	.15	.15
84°	.12	.13	.13	.14	.14	.15	.15	.16
85°	.12	.13	.13	.14	.14	.15	.15	.16
86°	.12	.13	.14	.14	.15	.15	.16	.16
87°	.13	.13	.14	.14	.15	.15	.16	.16
88°	.13	.13	.14	.15	.15	.16	.16	.17
89°	.13	.14	.14	.15	.15	.16	.16	.17
90°	.13	.14	.14	.15	.16	.16	.17	.17
91°	.14	.14	.15	.15	.16	.16	.17	.18
92°	.14	.14	.15	.15	.16	.17	.17	.18
93°	.14	.15	.15	.16	.16	.17	.17	.18
94°	.14	.15	.15	.16	.17	.17	.18	.18
95°	.14	.15	.16	.16	.17	.17	.18	.19
96°	.15	.15	.16	.16	.17	.18	.18	.19
97°	.15	.15	.16	.17	.17	.18	.19	.19
98°	.15	.16	.16	.17	.18	.18	.19	.19
99°	.15	.16	.17	.17	.18	.18	.19	.20
100°	.15	.16	.17	.17	.18	.19	.19	.20

TABLE FOR REDUCING BAROMETER READINGS TO SEA LEVEL:
AMOUNTS TO BE ADDED

Elevation in feet	Temperature 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
100	.12	.12	.12	.12	.11	.11	.11	.11	.10	.10
200	.24	.24	.23	.23	.22	.22	.22	.21	.21	.20
300	.36	.36	.35	.34	.34	.33	.32	.32	.31	.30
400	.48	.47	.46	.46	.45	.44	.43	.42	.41	.40
500	.60	.59	.58	.57	.56	.55	.54	.53	.52	.51
600	.72	.71	.69	.68	.67	.65	.64	.63	.62	.61
700	.84	.82	.81	.79	.78	.76	.75	.73	.72	.71
800	.96	.94	.92	.90	.88	.87	.85	.84	.82	.81
900	1.08	1.06	1.03	1.01	.99	.97	.96	.94	.92	.90
1000	1.20	1.17	1.15	1.12	1.10	1.08	1.06	1.04	1.02	1.00
1100	1.31	1.29	1.26	1.23	1.21	1.19	1.16	1.14	1.12	1.10
1200	1.43	1.40	1.37	1.34	1.32	1.29	1.27	1.24	1.22	1.20
1300	1.55	1.51	1.48	1.45	1.42	1.40	1.37	1.35	1.32	1.30
1400	1.66	1.63	1.59	1.56	1.53	1.50	1.47	1.45	1.42	1.40
1500	1.78	1.74	1.70	1.67	1.64	1.61	1.58	1.55	1.52	1.49
1600	1.89	1.85	1.81	1.78	1.74	1.71	1.68	1.65	1.62	1.59
1700	2.00	1.96	1.92	1.89	1.85	1.81	1.78	1.75	1.72	1.69
1800	2.12	2.07	2.03	1.99	1.95	1.92	1.88	1.85	1.82	1.78
1900	2.23	2.19	2.14	2.10	2.06	2.02	1.98	1.95	1.91	1.88
2000	2.34	2.30	2.25	2.21	2.16	2.12	2.08	2.05	2.01	1.97
2100	2.46	2.41	2.36	2.31	2.27	2.22	2.18	2.14	2.10	2.07
2200	2.57	2.52	2.47	2.42	2.37	2.33	2.28	2.24	2.20	2.16
2300	2.68	2.63	2.57	2.52	2.47	2.43	2.38	2.34	2.30	2.26
2400	2.79	2.73	2.68	2.63	2.58	2.53	2.48	2.44	2.40	2.35
2500	2.90	2.84	2.79	2.73	2.68	2.63	2.58	2.54	2.49	2.45
2600	3.01	2.95	2.89	2.84	2.78	2.73	2.68	2.63	2.58	2.54
2700	3.12	3.06	3.00	2.94	2.88	2.83	2.78	2.73	2.68	2.63
2800	3.23	3.16	3.10	3.04	2.98	2.93	2.88	2.82	2.77	2.73
2900	3.34	3.27	3.21	3.15	3.09	3.03	2.97	2.92	2.87	2.82
3000	3.45	3.38	3.31	3.25	3.19	3.13	3.07	3.02	2.96	2.91
3100	3.56	3.49	3.42	3.35	3.29	3.23	3.17	3.11	3.06	3.00
3200	3.66	3.59	3.52	3.45	3.39	3.32	3.26	3.21	3.15	3.10
3300	3.77	3.69	3.62	3.55	3.49	3.42	3.36	3.30	3.24	3.19
3400	3.88	3.80	3.72	3.65	3.59	3.52	3.46	3.40	3.34	3.28
3500	3.98	3.90	3.82	3.75	3.68	3.62	3.55	3.49	3.43	3.37
3600	4.09	4.01	3.93	3.85	3.78	3.71	3.65	3.58	3.52	3.46
3700	4.19	4.11	4.03	3.95	3.88	3.81	3.74	3.67	3.61	3.55
3800	4.30	4.21	4.13	4.05	3.98	3.90	3.83	3.77	3.70	3.64
3900	4.40	4.32	4.23	4.15	4.08	4.00	3.93	3.86	3.79	3.73
4000	4.51	4.42	4.33	4.25	4.17	4.10	4.02	3.95	3.89	3.83
4100	4.61	4.52	4.43	4.35	4.27	4.19	4.12	4.05	3.98	3.91
4200	4.71	4.62	4.53	4.45	4.37	4.29	4.21	4.14	4.07	4.00
4300	4.82	4.72	4.63	4.54	4.46	4.38	4.30	4.23	4.15	4.08
4400	4.92	4.82	4.73	4.64	4.56	4.47	4.39	4.32	4.24	4.17
4500	5.02	4.92	4.84	4.74	4.65	4.57	4.49	4.41	4.33	4.26
4600	5.12	5.02	4.93	4.84	4.75	4.66	4.58	4.50	4.42	4.35
4800	5.32	5.22	5.12	5.02	4.93	4.85	4.76	4.68	4.60	4.52
5000	5.52	5.42	5.32	5.22	5.12	5.03	4.94	4.86	4.77	4.69

TABLE FOR FINDING RELATIVE HUMIDITY: PERCENTAGES

Dry therm. (air temp.)	Difference between Dry and Wet-bulb Thermometers													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	68	35	3											
2	71	41	12											
4	73	46	19											
6	75	50	25	1										
8	77	54	31	9										
10	79	57	36	15										
12	80	60	41	21	3									
14	82	63	45	27	10									
16	83	66	49	33	16	0								
18	84	68	53	38	22	7								
20	85	70	56	42	28	14								
22	86	72	59	45	32	19	7							
24	87	74	61	49	36	24	12	0						
26	88	75	64	52	40	29	18	7						
28	88	77	66	55	44	33	23	12	2					
30	89	78	68	57	47	37	27	17	8					
32	90	79	69	60	50	41	31	22	13	4				
34	90	81	72	62	53	44	35	27	18	9	1			
36	91	82	73	65	56	48	39	31	23	14	6			
38	91	83	75	67	59	51	43	35	27	19	12	4		
40	92	84	76	68	61	53	46	38	31	23	16	9	2	
42	92	85	77	70	62	55	48	41	34	28	21	14	7	0
44	93	85	78	71	64	57	51	44	37	31	24	18	12	5
46	93	86	79	72	65	59	53	46	40	34	28	22	16	10
48	93	87	80	73	67	60	54	48	42	36	31	25	19	14
50	93	87	81	74	68	62	56	50	44	39	33	28	22	17
52	94	88	81	75	69	63	58	52	46	41	36	30	25	20
54	94	88	82	76	70	65	59	54	48	43	38	33	28	23
56	94	88	82	77	71	66	61	55	50	45	40	35	31	26
58	94	89	83	77	72	67	62	57	52	47	42	38	33	28
60	94	89	84	78	73	68	63	58	53	49	44	40	35	31
62	94	89	84	79	74	69	64	60	55	50	46	41	37	33
64	95	90	85	79	75	70	66	61	56	52	48	43	39	35
66	95	90	85	80	76	71	66	62	58	53	49	45	41	37
68	95	90	85	81	76	72	67	63	59	55	51	47	43	39
70	95	90	86	81	77	72	68	64	60	56	52	48	44	40
72	95	91	86	82	78	73	69	65	61	57	53	49	46	42
74	95	91	86	82	78	74	70	66	62	58	54	51	47	44
76	96	91	87	83	78	74	70	67	63	59	55	52	48	45
78	96	91	87	83	79	75	71	67	64	60	57	53	50	46
80	96	91	87	83	79	76	72	68	64	61	57	54	51	47
84	96	92	88	84	80	77	73	70	66	63	59	56	53	50
88	96	92	88	85	81	78	74	71	67	64	61	58	55	52
92	96	92	89	85	82	78	75	72	69	65	62	59	57	54
96	96	93	89	86	82	79	76	73	70	67	64	61	58	55
100	96	93	90	86	83	80	77	74	71	68	65	62	59	57

TABLE FOR FINDING RELATIVE HUMIDITY: PERCENTAGES (*Continued*)

Dry therm. (air temp.)	Difference between Dry and Wet-bulb Thermometers													
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
46	4													
48	8	3												
50	12	7	2											
52	15	10	6	0										
54	18	14	9	5	0									
56	21	17	12	8	4									
58	24	20	15	11	7	3								
60	27	22	18	14	10	6	2							
62	29	25	21	17	13	9	6	2						
64	31	27	23	20	16	12	9	5	2					
66	33	29	26	22	18	15	11	8	5	1				
68	35	31	28	24	21	17	14	11	8	4	1			
70	37	33	30	26	23	20	17	13	10	7	4	1		
72	39	35	32	28	25	22	19	16	13	10	7	4	1	
74	40	37	34	30	27	24	21	18	15	12	9	7	4	1
76	42	38	35	32	29	26	23	20	17	14	12	9	6	4
78	43	40	37	34	31	28	25	22	19	16	14	11	9	6
80	44	41	38	35	32	29	27	24	21	18	16	13	11	8
82	46	43	40	37	34	31	28	25	23	20	18	15	13	10
84	47	44	41	38	35	32	30	27	25	22	20	17	15	12
86	48	45	42	39	37	34	31	29	26	24	21	19	17	14
88	49	46	43	41	38	35	33	30	28	25	23	21	18	16
90	50	47	44	42	39	37	34	32	29	27	24	22	20	18
92	51	48	45	43	40	38	35	33	30	28	26	24	22	19
94	52	49	46	44	41	39	36	34	32	29	27	25	23	21
96	53	50	47	45	42	40	37	35	33	31	29	26	24	22
98	53	51	48	46	43	41	39	36	34	32	30	28	26	24
100	54	52	49	47	44	42	40	37	35	33	31	29	27	25

TABLE FOR FINDING RELATIVE HUMIDITY: PERCENTAGES (*Continued*)

Dry therm. (air temp.)	Difference between Dry and Wet-bulb Thermometers													
	29	30	31	32	33	34	35	36	37	38	39	40	41	42
76	1													
78	4	1												
80	6	4	1											
82	8	6	4	1										
84	10	8	6	4	2									
86	12	10	8	6	4	2								
88	14	12	10	8	6	4	2							
90	16	14	12	10	8	6	4	2	0					
92	17	15	13	11	9	8	6	4	2	0				
94	19	17	15	13	11	9	8	6	4	2	1			
96	20	18	17	15	13	11	9	7	6	4	3	1		
98	22	20	18	16	14	13	11	9	7	6	4	3	1	
100	23	21	19	18	16	14	12	11	9	7	6	4	3	1

APPENDIX III

THE CONSTRUCTION OF A WEATHER MAP

The student will learn to read a weather map more rapidly and understand it more thoroughly by first making one. The table on p. 411 gives the data sent into the United States Weather Bureau from all the stations on the morning of March 15, 1899.

Blank maps, form DD, giving the location of the stations, may be obtained from the Bureau at $1.55 per thousand. Let the student write below the circle indicating each station upon the map the temperature at that station, and then proceed to draw the isotherms for each ten degrees. Draw first the isotherm of 30°, which passes through all stations having a temperature of 30° and separates those having a higher temperature from those having a lower. Starting a little north of Boston, it runs westward north of Albany, south of Parry Sound, Sault Ste. Marie, and Marquette, east of St. Paul and Des Moines, through Concordia, Oklahoma, and El Paso, and thence passes northward east of Grand Junction. In a similar manner draw isotherms at ten-degree intervals from 70° to – 30°.

Upon another blank map write the pressure at each station, and proceed to draw the isobars for each tenth of an inch. First find the area of low pressure, which appears from inspection of the table to be the Lake region, with Grand Haven as a center. Inclose the center with the isobar of 29.60 inches, which passes south of Sault Ste. Marie, east of Dubuque and Davenport, north of Indianapolis, and west of Detroit. Locate the area of high pressure in Northwest Territory, and inclose it with the isobar of 30.70 inches. These will indicate the general pattern of the isobars. When the isobars are completed and numbered, draw upon the same map at each station a small arrow *flying with the wind*, as given in the table. Transfer the isotherms to the map of isobars. The two sets of lines may be drawn in different colors. Attach to each arrow the symbol used upon weather maps for clear, fair, cloudy, rain, or snow, as the case may be at each station; or the area where the table indicates cloud, rain, or snow may be shaded lightly, and the areas where rain or snow is falling shaded more deeply.

Observe upon the map thus drawn: (1) The pressure slopes between Grand Haven and Boston, Norfolk, Montgomery, Valentine, and Minnedosa; between Qu'Appelle and San Antonio; between Swift Current

Observations taken at 8 A.M., 75th Meridian Time

Districts and Stations	Barometer readings, in inches.	Temperature.	Wind direction and velocity, in miles per hour	Sky and precipitation.
Atlantic Coast.				
Boston	30.46	34	S.E. 12	cloudy
Albany	30.34	32	S.E. 20	"
New York	30.32	38	E. 34	"
Philadelphia	30.24	40	S.E. 14	rain
Washington	30.16	36	N. Lt	"
Lynchburg	30.12	36	N.E. Lt.	"
Norfolk	30.12	42	N. Lt.	"
Jacksonville	30.12	66	S. 8	clear
Tampa	30.14	68	S.E. 12	cloudy
Gulf States.				
Atlanta	30.02	50	N.E. 6	rain
Mobile	30.06	70	S.W. Lt.	fair
Montgomery	29.98	70	S. 12	cloudy
Vicksburg	30.08	62	N.W. 12	fair
New Orleans	30.06	70	S.W. 6	"
Shreveport	30.14	54	N.W. 8	clear
Fort Smith	30.16	38	W. 12	"
Little Rock	30.06	48	W. 12	fair
Galveston	30.06	66	N.W. 6	cloudy
Palestine	30.18	52	N.E. 6	"
San Antonio	30.04	62	N. 14	"
Fort Worth	30.24	42	N. 8	fair
Ohio Val. and Ten.				
Indianapolis	29.64	56	S.W. 28	clear
Pittsburg	29.88	42	S. 6	rain
Cincinnati	29.74	58	S. 14	cloudy
Columbus	29.72	54	S. 12	"
Louisville	29.76	58	S. 14	"
Chattanooga	29.98	50	S.E. Lt.	rain
Memphis	30.02	56	W. 14	fair
Nashville	29.92	60	W. 8	cloudy
Parkersburg	29.82	50	S.E. 14	"
Lake Region				
Chicago	29.54	40	S.W. 36	cloudy
Detroit	29.64	42	S. 10	"
Grand Haven	29.50	40	S. 12	"
Marquette	29.68	24	W. 12	snow
Sault Ste. Marie	29.62	24	E. 14	"
Duluth	29.90	26	N.W. 18	"
Cleveland	29.68	48	S.E. 30	rain
Buffalo	29.78	40	S. 18	cloudy
Parry Sound	29.74	28	S.E. 36	"
White River	29.80	18	N. Lt.	snow

Districts and Stations	Barometer readings, in inches.	Temperature.	Wind direction and velocity, in miles per hour.	Sky and precipitation.
Upper Miss. Val.				
Cairo	29.88	54	S.W. 20	clear
St. Louis	29.84	40	W. 28	cloudy
Springfield, Ill.	29.74	38	W. 20	"
Keokuk	29.84	36	W. 26	"
Davenport	29.62	34	W. 16	rain
Des Moines	29.96	28	N.W. 20	cloudy
Dubuque	29.64	32	N.W. 20	snow
St Paul	29.88	24	N.W. 16	fair
Missouri Valley.				
Kansas City	30.08	32	N.W. 12	cloudy
Springfield, Mo.	30.10	28	N.W. 26	clear
Concordia	30.30	30	N.W. 24	"
Omaha	30.10	24	N.W. 16	cloudy
Sioux City	30.12	18	N.W. 28	"
Huron	30.20	10	N.W. 30	"
Bismarck	30.58	− 4	N.W. 8	clear
Moorhead	30.30	8	N.W. 20	cloudy
Northwest Ter.				
Calgary	30.62	−16	0	clear
Minnedosa	30.70	−12	S.W. Lt.	"
Prince Albert	30.68	−32	0	fair
Swift Current	30.72	−12	0	cloudy
Qu'Appelle	30.64	− 6	Lt.	"
Rocky Mt. Slopes.				
Havre	30.42	zero	N.E. 8	clear
Helena	30.40	2	W. Lt.	snow
Miles City	30.50	2	N. Lt.	fair
Rapid City	30.50	4	N.E. 6	"
Valentine	30.48	4	N.W. 12	clear
North Platte	30.48	8	N.W. 14	"
Cheyenne	30.46	8	S. 8	"
Lander	30.36	4	S.W. Lt.	cloudy
Salt Lake City	30.00	40	S.E. 6	"
Denver	30.38	14	N.E. 18	clear
Pueblo	30.30	18	E. Lt.	fair
Santa Fé	30.18	24	0	clear
El Paso	30.14	30	N.E. Lt.	"
Abilene	30.26	36	N. 6	"
Amarillo	30.30	22	N. 14	"
Oklahoma	30.24	30	N. 14	"
Dodge City	30.38	18	N.W. 12	"
Wichita	30.30	24	N.W. 14	"
Grand Junction	30.14	32	E. 20	cloudy

and Salt Lake City. (2) The direction of the wind compared with that of the isobars and of the pressure slopes; the general air movement in the cyclone. (3) The wind velocities near the center of low pressure; near the center of high pressure. (4) The course of the isotherms across the cyclone; across the anticyclone. (5) The position of the areas of cloud and of rain or snow in relation to the cyclone.

Account for all these conditions. Make a forecast of the weather for March 15 and 16, 1899, at the place where you live.

This exercise may be repeated as often as desired, by giving the students data obtained from other weather maps. Consult Ward's Practical Exercises in Elementary Meteorology.

Daily weather maps may usually be obtained on request from any Weather Bureau Station.

APPENDIX IV[1]

REFERENCE BOOKS

The following list of standard books and periodicals is not intended to be a complete bibliography of the subject, but it comprises a large part of the literature in English, other than regular text-books on physical geography, available for the student and teacher of that subject. As a rule, the best books are named first under each topic. See Hints to Teachers and Students on the Choice of Geographical Books, Mill, $1.25, Longmans, Green, & Co.

General References

The International Geography. $3.50. D. Appleton & Co., N.Y.

Physiography, Huxley. $1.80. Macmillan.

Our Earth and Its Story, Brown. 3 Vols., $9.75. Cassell & Co., N.Y.

[1] Abbreviations used in this appendix: A. G., American Geologist (Minneapolis); A. J. S., American Journal of Science (New Haven); B. A. G. S., Bulletin (Journal) of the American Geographical Society (N.Y.); B. G. S. A., Bulletin of the Geological Society of America (Rochester); G. J., Geographical Journal (London); G. S., Geological Survey (Washington); J. G., Journal of Geology (Chicago); J. S. G., Journal of School Geography (Lancaster, Pa.); N., Nature (London); N. G. M., National Geographic Magazine (Washington); N. G. Mon., National Geographic Monographs; P. S. M., Popular Science Monthly (N.Y.); S., Science *(Lancaster, Pa.)*; S. G. M., Scottish Geographical Magazine (Edinburgh); S. R., *Report of the* Smithsonian Institution (Washington).

Outlines of the Earth's History, Shaler. $1.75. Appleton.

Annual Reports, Monographs, and Bulletins of the United States Geological Survey. Apply to the Director, Washington, D.C. (Abbrev. G. S.)

Reports of the Geological Surveys of the various states.

Annual Report of the Smithsonian Institution. Apply to the Secretary, Washington, D.C. (Abbrev. S. R.)

Periodicals

National Geographic Magazine. $2.50. Washington, D.C. (Abbrev. N. G. M.)

Bulletin (Journal) of the American Geographical Society. $4.00. N.Y. (Abbrev. B. A. G. S.)

Geographical Journal, $6.00. London, Eng. (Abbrev. G. J.)

Scottish Geographical Magazine. $5.00. Edinburgh, Scotland. (Abbrev. S. G. M.)

Journal of School Geography. $1.00. Lancaster, Pa. (Abbrev J. S. G.)

Bulletin of the American Bureau of Geography. $1.00. Winona Minn.

Journal of Geology. $3.00. Chicago, Ill. (Abbrev. J. G.)

Bulletin of the Geological Society of America. $5.00. Rochester, N.Y. (Abbrev. B. G. S. A.)

American Geologist. $3.50. Minneapolis, Minn. (Abbrev. A. G.)

American Journal of Science. $6.00. New Haven, Conn. (Abbrev. A. J. S.)

Science. $5.00. Lancaster, Pa. (Abbrev. S.)

Nature. $6.00. London, Eng., and New York. (Abbrev. N.)

Popular Science Monthly. $3.00. McClure, Phillips & Co., N.Y. (Abbrev. P. S. M.)

Book I

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